WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

Final Environmental Impact Statement

The Use of Dispersants as a Management Tool for Controlling Petroleum Spills

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FACT SHEET

A. PROJECT TITLE

The use of dispersants as a management tool for controlling oil spills.

B. PROJECT DESCRIPTION

The State of Washington proposes to adopt a management plan for using dispersants as one means of controlling oil spills in the coastal and marine waters of the state. Currently, there are a number of types of dispersants available for use in the United States. The management plan will be directed at: if, when, and how any of these dispersants should be used in Washington waters.

C. NAME AND ADDRESS OF PROPONENT:

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G. LIST OF LICENSES AND APPROVALS REQUIRED:

Department of Ecology Dispersant Management Plan approval.

H. PRINCIPAL CONTRIBUTORS:

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I. DATE FINAL EIS ISSUED:

June 30, 1993

J. AGENCY ACTION:

Dispersant Management Plan is anticipated to be effective within one month of the completion of the final EIS.

K. COST FOR EIS COPIES:

Single copies of this EIS are available from Ecology at no cost while supplies last - cost of reproduction after that.

CHAPTER 1 - SUMMARY

The State of Washington is in the process of adopting a management plan which allows for limited preapproval for the use of dispersants as one means of controlling spills in the coastal waters of the state. The plan is divided into: (1) an authorization process for preapproval of dispersant use and (2) guidelines and standards that control the utilization of dispersants in subregions authorized for use. The purpose of the EIS is to evaluate where and when the use of dispersants would be preapproved. Once the EIS is complete standards and guidelines plus a monitoring plan will be developed to implement the selected alternative.

It was apparent early on in the review of dispersant literature that a great deal of uncertainty existed as to both the effectiveness and toxicity of dispersants. Available information about both the effects and effectiveness of dispersants was inconclusive but there appeared to be some merit to the thought that under certain conditions dispersants appear to offer a degree of protection greater than might be proved without their use. Rather than repeat a similar type review the State of Washington chose to use a biological risk analysis as an alternative way to determine when dispersants might be authorized.

Five dispersant-use alternatives were evaluated:

Alternative NC (No change)
Alternative A (No dispersant use)
Alternative B (Blanket preapproval)
Alternative C (Selected preapproval - preferred)
Alternative D (Selected preapproval)

The coastal and marine waters of the state were divided into 15 regions and 132 subregions, as described in WAC 173-183 (Appendix A), for the purposes of preapproval of dispersants in specific subregions. The biological/sensitivity evaluation was based on subregion specific rankings of marine wildlife and habitat resources describing seasonal variations in abundance and distribution (Appendix C). Five priority habitats were considered for protection conferred through the use of dispersants remote from these habitats. The five priorities were habitats for birds and marine mammals, eelgrass beds, kelp beds, and salt marshes.

Fish scores (marine fish, shellfish and anadromous fish) were summed in each proposed dispersant use subregion and then compared to the bird and marine mammal values for the same subregion. Use or non-use of dispersants was governed by IF-THEN scenarios which differed by alternative. The IF-THEN scenario conferred different biological protection strategies by region and subregion. Using Subregion 2 (Outer Strait of Juan De Fuca) as the region of concern, the compensation table ranking scores for the natural resources were determined for the four seasons of the year (Appendix C, Tables 1-4). For example, during the spring season (Appendix C, Table 1) the natural resource values were determined to be: sum of fish values = 15, and the bird and marine mammal values = 4. The scenario "IF the sum of fish values exceed 9 and the bird and mammal values are equal to or less than 4, THEN dispersant use is not allowed" was then applied resulting in category "3", No Dispersant Use (Figure 1).

The preapproval determinations for all five dispersant-use alternatives are shown by season and region in Tables 1-4. This information shows that Alternative C (preferred) is less restrictive than the current policy (Alternative NC, conditional use for all areas) but still retains a high level of protection for natural resources.

Uncertainty about the effects of dispersants on marine fishery resources have led the state to select Alternative C as the preferred alternative. Dispersants are known to distribute the oil slick through a much greater water volume which is alive with larval and juvenile fish at certain seasons. Consequently, the state has chosen to select an alternative that features non-use of dispersants during seasons when the risk to these early life stages is significant. Significant risk was defined as a score of three or greater for the three fishery groups (marine fish, shellfish, and salmon). In the event that there are significant bird or marine mammal concerns, or a significantly vulnerable shoreline, a case by case scenario is allowed when fish values are three or less. If these conditions are met a dispersant use decision can be made. The Alternative C decisions are summarized by area and season in Table 5.

Due to the continued concern over the use of dispersants, as part of the preferred alternative we have chosen to create a dispersant use support team with the following direction:

(1) It will be coastwise and involve the states of Washington, Oregon, California, the federal government, and British Columbia, and

(2) The team will design a monitoring plan, be trained in this specialized field, direct efficacy testing in field situations, and evaluate study results.

When the team is ready dispersants will be used and evaluated on a spill of opportunity. Alternative C as described in this EIS will serve as Washington State's interim dispersant use policy until the coastwise effort offers a new approach.

The team will be created under the auspices of the States/B.C. Task Force to conduct additional research and develop a consistently applied dispersant use policy for the Pacific Coast.

CHAPTER 2 - PURPOSE AND NEED

The continuing number and frequency of oil spills within the marine and freshwater regions of Washington state have generated a great deal of legislative and governmental interest in strategies for oil spill prevention and cleanup. Programmatically, three general areas have been explored by the state in an attempt to determine the optimum strategy for prevention and control of petroleum spills:

1. Limit the transport of oil into Washington waters where risks to the environment are high.

2. Minimize the potential for spills through design, construction, and operation of transport modes with the greatest spill prevention capability.

3. Minimize the impacts to the environment through control and cleanup methods and procedures.

Oil spill control measures must be decided quickly during a spill response. This is especially true for dispersants which are effective only if applied very soon after a spill has occurred. The present federal/state decision process involves case-by case-approval. This process is considered cumbersome by some and thought to impede and/or prevent the use of dispersants. For this reason, it has been suggested that dispersant use should be preapproved whenever possible.

Initially, Clean Sound contracted with Woodward-Clyde, Inc. consultants to prepare a preliminary report examining preapproved use of dispersants. That report recommended liberal use of dispersants in Washington waters. The results of that assessment and additional material were used to develop this EIS. The State Environmental Policy Act (SEPA) requires an EIS whenever a government action is likely to have a significant adverse impact on the environment.

The purpose of this environmental impact statement (EIS) is to propose dispersant use in selected marine and estuarine waters as one means of controlling oil spills in the water of Washington State. The proposal includes application of limited preapproved dispersant use as recommended by the state and federal Regional

Response Team (RRT). This preapproval was based on the sensitivity of natural resources in predesignated subregions with consideration given to seasonal variations in distribution and abundance. The EIS is designed to evaluate a series of alternatives based on this concept. The coastal and marine waters are segregated into 15 broad regions which are further divided into 132 sub-regions. These sub-regions are then evaluated for dispersant use designation based on potential seasonal biological risks to the environmental resources.

The EIS describes five alternatives for managing the use of dispersants in the coastal and marine environment. Included is one alternative that is the preferred, or the "proposed action." For each alternative, the EIS describes the physical environment and the biological resources that would be affected. The environmental consequences of implementing each alternative are also evaluated.

2.1 What are Dispersants?

With the increase of marine oil transport in the 1960's and 1970's there was a concomitant recognition of environmental damage and an increase in concern about the prevention and control of oil spills. Public reaction to the Torrey Canyon and other spills precipitated development and study of new techniques to reduce environmental impacts from spills. Among those techniques were mechanical recovery and the use of chemical agents, especially dispersants.

Dispersants are solvents and agents for reducing surface tension. They are used to remove oil slicks from the surface of the water. The treated oil moves down into the water column as fine droplets where it is dispersed by currents and subject to natural processes such as biodegradation. Dispersants are made up of several ingredients, the most important of which are surfactants - known loosely as detergents. Surfactants are molecules with both water- and oil-soluble properties. The main surfactants employed in dispersants have both an affinity for oil and an affinity for water. The surfactant adheres to both the oil and water to thus produce the finely dispersed droplets of oil-surfactant molecules. Most dispersants also contain a solvent, either hydrocarbon or alcohol/glycol based.

Dispersants commercially available are of two primary types:

- "Conventional" hydrocarbon-based dispersants contain primarily hydrocarbon solvents and 10-25 percent surfactants; the percentage varies as a function of the physical properties (e.g., viscosity, pour point) of the target petroleum. These dispersants are applied full-strength to spilled oil. Successive generations of this type of dispersant have significantly reduced the toxicity by using aromatic-free solvent.

- Concentrated dispersants contain alcohol or glycol based solvents, and a larger component of surfactant agent. When the concentrate is applied to the oil spill it "self-mixes"; dilution with seawater before application is also possible, although with the application of dispersants by specialized aircraft, this practice has been largely discontinued.

CHAPTER 3 - LEGAL REQUIREMENTS

3.1 State

Washington law (90.56 RCW) states that it is the obligation of any person owning or having control over oil entering waters of the state to immediately collect and remove it. The law further states that if it is not feasible to collect and remove the oil, said person shall take all practicable actions to contain, treat, and disperse it. Chapter 90.48 RCW also authorizes the director of Ecology to prohibit or restrict the use of any chemicals or other dispersant or treatment materials proposed for use whenever it appears that the use would be detrimental to the public interest.

In practice this has meant that the person responsible for the spill or other parties involved in spill control and management must obtain approval from the Director of Ecology prior to using a chemical dispersing agent as means of treatment. However, since the decision as to whether or not to use dispersants is needed within a short time frame to be effective, a better decision tool is required. Since significant environmental damages may be prevented by a rapid application of dispersants, the present case-by-case decision process has effectively eliminated the use of chemicals to control or disperse spills. Preapproval would allow the On Scene Coordinator (OSC) to authorize dispersant use where so designated in the management plan.

3.2 Federal

The use of dispersants and other chemical agents in navigable waters of the USA is governed by a provision of the National Contingency Plan. This plan requires the concurrence of the EPA representative and the state(s) concerned before a chemical agent can be used. Thus, there is a dual approval authority. The federal OSC can approve the use of dispersants or chemicals without concurrence if the use of such a product is necessary to prevent or substantially reduce a hazard to human life.

Since oil spills impact resources beyond state boundaries and since there are a variety of federal and state agencies with concern and authority, a Regional Response Team (RRT) dispersant use subcommittee has been established in Region X to provide technical advice and assistance to the Federal On Scene Coordinator during a response action. The primary function of the RRT is to ensure that the agencies in the region are prepared to provide this assistance. The RRT acts as a coordinating body that brings federal, state, and local government agencies together. In addition, it provides a mechanism for planning and preparedness activities before a response action is initiated.

CHAPTER 4 - METHODS AND MATERIALS

The EIS presents a preferred alternative to be used primarily by state, federal, and responsible party personnel implementing dispersant use decisions during major oil spills in the coastal waters of Washington. The goal is to optimize protection for natural resources. This goal would be accomplished by establishing specific dispersant use sub-regions within state waters. This alternative provides the on-scene coordinator with guidance for making decisions on dispersant use based on criteria which include limited preapproval.

The preferred alternative is designed to: 1) reduce the time required to determine if dispersant use is appropriate and 2) attempt to predetermine the overall impacts to the environment through the establishment of biological resource evaluations. The alternative would also guide the appropriate use of dispersants during a petroleum spill. The OSC would quickly authorize use when in his or her professional judgment the environmental conditions and appropriate guidelines and standards were adequate so that dispersant use might result in less environmental damage than solely relying on other methods.

The preferred alternative embodies the provisions of state and national contingency plans and other guiding documents. Proposed dispersant use determinations, standards, guidelines, and management direction are consistent with these provisions.

Projected resource values are estimates and will be updated every three years.

4.1 Outline of Analytical Process

Five dispersant-use alternatives were developed using the following planning approach:

1. Identification of public dispersant issues, concerns, and opportunities.

2. Collection of data from resource inventories and creation of a comparative resource ranking system (WAC 173-183); the issues and concerns and opportunities help determine what data was collected.

3. Development of analysis areas by grouping elements of resource data for selected resource producing regions assumed to be somewhat homogeneous in their capability to produce outputs and effects in response to management options.

4. Development of a range of potential alternatives assigning unique combinations of management strategies which group analysis areas throughout the coastal and estuarine waters. Each potential alternative will achieve a specific objective or set of objectives in responding to the issues.

5. Analyze the potential alternatives for outputs, costs and effects.

4.2 Issues, Concerns and Opportunities

Historically, an informal policy in Washington has prohibited the use of chemical agents as a control strategy except under conditions threatening life, health, and critical resources, such as endangered species. The "policy" in Washington was modified in late summer 1989, when the "Exxon Valdez" was enroute from Alaska to San Diego, to permit the controlled use of dispersants in water of >100 m in depth and further than 10 miles offshore. As far as is known, however, no chemical agents have been used at any time on marine oil spills in the region.

Using dispersants for control of oil spills in Washington has not been allowed to date because of concerns about potential negative impacts to fishery resources. Since oil spills impact resources beyond state boundaries, and since there are a number of federal and state agencies with concerns, the Regional Response Team (RRT), in 1989, requested that the state and federal government reconsider the use of preapproval for the use of dispersants in specified areas of the coastal and marine waters.

The main concerns about chemical dispersant use in oil spill control are as follows:

1. Biological Effects Dispersed oil may adversely affect shallow subtidal benthos in the short term if water depth and movement are insufficient to remove and dilute the oil. A recent summary (NRC, 1989) concluded

that laboratory and meso-scale field experiments have shown that the acute biological effects of dispersed oil are no worse than those of untreated oil, per unit of oil. Nevertheless, some benthic organisms (such as mollusks) are apparently more acutely sensitive to dispersed oil, although in the longer term it was concluded that the use of dispersant reduced bioaccumulation. The key to ecological damage would therefore appear to be a reduction of chronic exposure (Boehm, et al., 1985,1987; Gilfillan et al., 1985). This is best achieved if stranding and re-working of the untreated oil are avoided or at least reduced. One way of doing this, if mechanical recovery from the water surface is not possible, is to apply chemical dispersant.

2. Shoreline Impacts Partially-dispersed oil which was treated just offshore but which failed to disperse completely often shows increased effects on shoreline flora and fauna. Toxic effects of oil plus dispersant mixtures exceeding those of either oil or dispersant alone were observed by Crothers (1983) on a sheltered rocky shore (for limpets and periwinkles). However, these effects were short-lived. Baker et al. (1984) and Howard et al. (1989) also found that oil plus dispersant mixtures were more damaging than oil or dispersant alone on temperate seagrass beds. Thorhaug et al. (1986) had found similar results for subtropical and tropical seagrasses, and a great variation in effects depending on the seagrass species concerned. on saltmarshes, both oil and dispersed oil will usually have adverse effects (Baker et al., 1984). Some of the adverse effects of partially dispersed oil on shorelines are probably due to the increased sediment penetration of some oil and dispersant mixtures (Little and Baker, 1989).

3. Aesthetics There are aesthetic and public relations concerns over the use of dispersants. Operations may successfully reduce the layer thickness of oil which strands, but any oil on the shore may be construed by the public as a failure of the entire dispersant operation. The role of any single oil spill countermeasure cannot be regarded as a panacea for cleanup. The physiochemical limitations and the window of opportunity for dispersant use can perhaps be better explained to the public and pressure groups as well as to other closely affected groups, such as fishermen. Then it will be possible to judge more objectively between dispersed and untreated oil trade-offs, since there will be less risk of the dispersant being judged on the basis of a suboptimal or ineffective operation. It is, however, still difficult to demonstrate dispersant effectiveness in real oil spills as shown by the "Ixtoc I",

"Chevron Main Pass," "Torrey Canyon," and "Sivand" spills. The main limitations to dispersant effectiveness are due to oil type (waxy crudes, heavy fuels or emulsified oil) where the viscosity much exceeds 2000 cSt or the pour point exceeds the ambient water temperature; weather (fog and/or sea state less than 2 and geographic and location factors (near industrial water intakes as well as ecologically sensitive areas). Additionally, it will usually not be possible to spray close to inhabited shorelines due to real or perceived human health threats posed by lateral wind drift of the dispersant.

4. <u>Toxic Effects</u> Some of the more toxic, low-molecular-weight hydrocarbons evaporate or dissolve relatively early in an oil spill. There is a concern that use of chemical dispersants will take more of these fractions into the water column than would have occurred beneath untreated slicks. The API 1979 field trials (McAuliffe et al., 1981) showed that concentrations and exposure times of chemically dispersed oil did in fact exceed those beneath the untreated slick, although no significant enrichment of hydrocarbons occurred beneath a depth of 10 meters. The near-surface enrichment must take place for dispersants to achieve their intended goal - removal of oil from the sea surface. No evidence has been found for increased toxicity of dispersed oil when modern formulations have been used. Increased exposure to hydrocarbons may take place, however, especially where water circulation is insufficient, but the dispersed oil droplets have not been shown to differ from the untreated oil in composition. Enhanced biodegradation of the dispersed oil is a secondary benefit derived from a successful dispersant operation. Dispersed oil concentrations in open water are much lower than those observed to have caused effects in laboratory bioassays (NRC, 1989).

5. <u>Perceptions</u> There is the concern that dispersion of surface oil is not a solution to the problem, but merely "out of sight, out of mind." It is, however, unrealistic to view dispersion simply in terms of sinking the oil. One way dispersion of oil;, however, may increase the effects of a spill is by increasing the area covered by sheen. This would increase the area potentially hazardous to birds and mammals (NRC, 1989). Although this remains a possible disadvantage which would offset the biological benefits to birds resulting from dispersant use, its occurrence has not been conclusively demonstrated. Similarly, the decision to not use dispersants is often made because of the perceived risks to fish populations. No measurable biological effects of either dispersed or

untreated oils to commercial fisheries have yet been reported, due to the mobility of the fish and much of their prey, the natural variability of their populations and, in some cases, the effect of overfishing (NRC, 1989). Hydrocarbon uptake by fish was increased experimentally when a hydrocarbon-based dispersant was added to the test media (McKeown, 1981). Also, fish can be killed when oil spills affect mariculture sites with moored fish cages, but, so far, no major impacts of oil spills have been recorded on wild fish populations (Duval et al., 1981).

Unfortunately, firm conclusions can not be drawn from the information presented. The primary conclusion which can be drawn from this information is that both the toxicity and effectiveness of dispersants depends on a number of factors, including type of oil, type of dispersant, weather conditions, and location. Therefore, the use of dispersants must be evaluated primarily on a case-by-case basis. A review of literature shows that the monitoring and evaluation of dispersant use impacts are totally insufficient to provide grounds for establishing a policy allowing wide spread application of dispersants without severe restraints.

4.3 Information and Data

Information was collected prior to, during, and following the identification of dispersant issues, concerns and opportunities. Several technical advisory teams assembled data on resources capabilities, conditions, trends, existing supplies and demand. Existing data were used and, in some cases, supplemented with new information.

4.4 Regional and Subregional Descriptions

For the purpose of the dispersant use analysis, the coastal and marine waters in and adjacent to Washington were divided into the same 15 regions (Appendix A, pages 17-19) used in the Oil Spill Compensation Schedule - WAC 173-183 (adopted from Wahl et al, 1981; and Wahl, personal communication, 1991).

Several regions described in the WAC were excluded from the analysis since they did not meet the minimum selection criteria for dispersant use - open water surface area of greater than 200 sq km and a midpoint distance to shoreline greater than 3 miles. The following regions did, however, meet these criteria and were consequently considered for dispersant use.

1. Region 1 - Outer Coast (Subregions 101-112)

This region lies along the western-most shores of Washington state and includes the important shallow embayments of Grays Harbor and Willapa Bay. Extensive sandy and rocky shores with significant kelp beds are distributed along the coast.

2. Region 2 - Strait of Juan de Fuca - Outer (Subregions 201-209)

This large region is bounded on the west by a line from Cape Flattery to Carmanah Point, Vancouver Island, and on the east by a line from Port Angeles to Race Rocks, British Columbia. It includes the waters of up to 300 m depth in mid-strait and small shallow bays and estuaries, such as Neah Bay, Clallam Bay, and Crescent Bay. Shorelines are characterized by rocky types with kelp beds.

3. Region 3 - Strait of Juan de Fuca - Inner (Subregions 301-317)

This region contains the eastern portion of the Strait of Juan de Fuca. Important zones include Port Angeles Bay, Dungeness Bay and Harbor, Sequim Bay, and extensive open shorelines. Ediz Hook and Dungeness Spit are the largest of a number of accreted gravel spits protecting embayments. A variety of other shoreline types are present, including rocky shorelines, mixed fine beaches, and particularly on the southern shores of the San Juan Islands, continuous rock strata formations.

4. Region 6 - Eastern Georgia Strait (Subregions 601-608)

This region essentially ends at the United States-Canada boundary. Shorelines are primarily sandy, mixed, and cobble, with bluffs backing beaches along part of the eastern shoreline. Eelgrass and kelp communities are present throughout the region.

5. Region 7 - Western Georgia Strait (Subregions 701-703)

This deepwater region is influenced by low salinity/high turbidity surface waters resulting from the Fraser River runoff. Offshore water depths range over 200 m. Shorelines are mixed gravel and sand, with associated kelp, and the shallow mud/sand bay with eelgrass at Tsawwassen.

6. Region 8 - Haro Straits (Subregion 801 & 802)

This deepwater region is the channel separating the San Juan Islands from Canadian waters. Haro Strait is up to 300 m deep with shore made up of rock strata with some sizable shallow shelf, low-beach component at Waldron Island.

For additional descriptions of the environments of these subregions refer to Appendix B.

4.5 Resource Evaluation and Rating

Teams of statewide technical experts ranked all resource values by season for coastal and marine waters (132 subregions) for purposes of developing a resource damage compensation table, WAC 173-183 (Appendix A). These resource ratings, referred to as Analysis of Resource Situation (ARS), were adopted for purposes of dispersant evaluation. The ranking system scored marine mammals, marine fish, shellfish, salmon, marine birds, intertidal and subtidal habitats and recreational resources on a 1-5 basis for all subregions.

The comparative resource evaluation leads to the selection of proposed preapproved dispersant use sub-regions based on the comparative resource values by subregion and season. For example, spring season values (ranking scores) for region 2 (Outer Juan de Fuca Straits) are given in Table 1. All decisions would be based on the fact that there are known tradeoffs associated with the use of dispersants and when these are weighed against the resource value to be protected, there may be times when the value of the resource protection outweighs the added potential loss to another resource value from the use of dispersants.

Each dispersant use decision is governed by a comparative natural resource evaluation, based on the resource type, number and sensitivity to oil and/or dispersants in each of the marine and estuarine subregions. Appendix C contains seasonal ARS tables for all subregions considered for dispersant use. Each resource rank is described on a 1-5 basis with 5 being the highest score attainable. Marine fish, salmon, shellfish, birds, habitats and marine mammals were selected for this analysis. For example, using Table 1 (same as Appendix C, Table 1) for subregion 201 the spring salmon, shellfish and marine fish resources are ranked as 5. Birds and marine mammals are ranked 3 and 4, respectively (Scoring is described in detail in Appendix A). Specific habitats designated for protection were identified in each subregion, e.g. subregion 203 has significant kelp beds.

The subregional scores (Tables 1-20, Appendix C) describe the present and, as a minimum, the desired future condition of natural resources in the marine and estuarine waters. The maintenance of these outputs and activities is considered to be the goal the state should meet via implementation of this policy.

4.6 Dispersant Use Decision Matrix - Seasonal Resource Advantage Evaluation

The value of using dispersants is prevention of sensitive inshore habitats, reducing hazards of birds and mammals, enhancing degradation of oil of chronic impacts on low energy habitats (NRC, 1989). The American Society for Testing and Materials (ASTI) system has selected five priority habitats that should be considered for protection conferred through the use of dispersants remote from identified sensitive habitats. The five priority habitats are birds and marine mammals, eelgrass beds, tidal flats, kelp beds and saltmarshes.

Dispersant use decisions are based on a comparison of fish, bird and marine mammal, and habitat resource values within the potential dispersant use region and adjacent subregions that might benefit from such use. Literature indicates that fish, birds and marine mammals, and habitat are the primary resources affected by oil spills. The tables shown in Appendix C compare the collective fish (shellfish, marine fish and anadromous fish) resources to bird and marine mammals, and habitat values The left half of each table lists comparative resource values.

The ARS scores were summed for the three fish groups and then compared to the bird and marine mammal values for the specific subregion. Nearshore habitats which might be protected were listed individually. Using Table 1 (Appendix C) as the example, subregion 201 for the spring season had a fish score of 15 and a marine mammal score of 4. Subregion 203 had a fish score of 15 while the bird score was 4. Kelp beds ("K" notation) are common in both subregions.

4.7 Selection of Dispersant Use Categories

Chemical dispersants would be authorized in regions when it is judged that the advantage of using the dispersant outweighs the impacts of allowing untreated oil to enter other sensitive environments or damage unique wildlife/fish populations. Four dispersant use decisions are possible in each subregion: Dispersant Use Recommended, Dispersant Use Acceptable, Dispersant Use Conditional, and No Dispersant Use (Lindstedt-Siva, J., 1989. The decision to use or not use dispersants is based on the known biological consequences of dispersant use in the specific region versus its use as a method to protect valuable fish and wildlife habitat and species in other areas.

Authorization for approval of dispersant use within any subregion was based on meeting all of the following criteria:

a. A critical evaluation of resources and habitats in the spill zone.

b. Potential of critical habitats remote from the spill site being impacted by undispersed oil;

c. Potential of critical aggregations of fish, birds, and marine mammals remote from the spill site being impacted by undispersed oil;

d. Meteorological and oceanographic conditions that suggest that the undispersed oil trajectory will, in fact, impact these remote fish and wildlife aggregations and/or habitats;

e. Assume adequate delivery system;

f. Environmentally acceptable dispersant available; and

g. Preliminary tests have shown that the RP can deliver a dispersant effectively.

4.8 Dispersant Use Direction

The actual decision by the OSC as to whether or not to authorize dispersant use will depend upon the oceanic and weather situation at the time. Each dispersant-use subregion was evaluated seasonally:

Winter - December, January, February
Spring - March, April, May
Summer - June, July, August
Fall - September, October, November

The dispersant-use policy is based on the use of slightly modified ecological standards and guidelines prepared under the auspices of the ASTI and American Petroleum Institute (API) Site-Specific Planning Project described by Lindstedt-Siva (1989). The API approach requires that the coastal and marine waters area be divided into three dispersant-use categories.

Dispersant Use Category 1 - Preapproval

Preapproval is warranted when the use of dispersants will prevent or reduce impacts to sensitive resources remote from the spill site. Minimum standards for preapproval include:

a. Water depth (>20 meters) and/or mixing energy are sufficient to allow dispersed oil to be rapidly diluted to low concentrations;

b. Distance from sensitive resources and nearshore subregions is far enough (> 3 miles) so that dispersant application operations and dispersed oil concentrations will not cause disturbance or damage;

c. A significant likelihood exists that oil spilled in this subregion will eventually impact sensitive resources;

d. The potential dispersant use subregion is larger than 200 sq km;

e. All subregional fish ARS values rank low relative to the wildlife values and/or sensitive habitat is protected.

Dispersant Use Category 2 - Case-by-case approval

The state will consider case-by-case dispersant use if all of the preapproval criteria are met except (e) which changes to:

e All subregional fish and wildlife have ARS values that are not significantly different, and sensitive habitats may by protected by dispersant use.

If these criteria are met, the state will consider dispersant use based on an analysis of the following information provided by the response organization:

a. Trajectory analysis of oceanographic currents, weather patterns and potential landfall areas (USCG);

b. Dispersant "window of time" for effective use (USCG);

c. Proposed dispersant application procedure (USCG/RP);

d. Overflight survey results (NRDA);

e. Monitoring plan design guidance (NRDA);

f. Monitoring plan (RP, must be approved by NRDA);

g. Application field test (RP; NRDA observer);

h. Model predicting concentration of dispersed oil in water column (NRDA).

i. Fish and wildlife Analysis of Resource Situation (ARS) scores.

In those cases where competing resources have equal ARS values it may be necessary to make case-by-case decisions as to the magnitude of the impact on certain resources. For example, if both fish and bird rankings scores are 5, hard decisions will have to be made. Since the dispersant matrix is dependent on general rankings the decision will have to be based on actual resource values at the time of the spill.

Generally, in those cases where, based on the above criteria, case-by-case dispersant use decisions are appropriate, the following procedures would be used:

a. The state OSC will request that the Natural Resource Damage Assessment Committee (NRDAC) evaluate the use of dispersants and provide to the OSC a recommendation for use/non-use. (This committee is comprised of the Washington State Departments of Wildlife, Parks, Fisheries, Health and Ecology, plus other ad hoc entities.)

b. The NRDAC will, on the basis of the spill data provided by the OSC and the environmental sensitivity rankings, make a recommendation whether to authorize dispersant use.

c. The NRDAC will communicate its dispersant decision to the OSC.

d. Should the decision involve multiple jurisdictions and those jurisdictions fail to reach agreement on a dispersant use/no-use decision, the default decision will be "no dispersant use".

Dispersant Use Category 3 - No dispersant use

Dispersant use not approved under any circumstances. This dispersant use decision results when subregional fish values are generally high while bird or marine mammal values are low.

CHAPTER 5 - ALTERNATIVES, INCLUDING THE PROPOSED ACTION

5.1 Introduction

This chapter describes alternative scenarios for the sue of dispersants in coastal and marine waters. The alternatives address different approaches to selectively minimize damage to the environment by use of dispersants during an oil spill. Preapproval strategies are dependent on using dispersants to reduce damage to specific high priority elements of the environment. Literature provides evidence that in certain cases, under certain conditions, and given a policy decision on the relative values of differing environmental resources, the answer is yes. The difficulty is in defining those conditions, cases and values in a timely manner.

In the broadest sense the alternatives regarding the use of chemical agents in oil spill control are:

1. A prohibition on the use of chemical dispersants for oil spill control;

2. A Case by case approval of Dispersants after the spill;

3. Preapproval of Dispersants to control oil spills under specified conditions;

4. Blanket preapproval of dispersant

The alternatives addressed in this EIS are:

1) Distributed to provide a broad range of dispersant use opportunities;

2) Formulated to facilitate analysis of opportunity costs, resource protection and environmental tradeoffs;

3) Designed to provide different ways to address and respond to specific opportunities for dispersant use.

5.2 Analysis Prior to Formulation of Alternatives

Dispersant use is a very controversial topic within the arena of oil spill management. A great deal of data must be considered in order to identify the many inputs, outputs, costs, benefits and environmental effects of differing dispersant use strategies. WAC 173-183 describes in detail the analysis of natural resource values for all coastal and marine waters of the state. ASTI and NRC dispersant summary documents form the basis for the evaluation of dispersants and the designation of dispersant use categories.

5.3 Alternatives Considered in Detail

The alternatives considered in detail all specify different ways of managing the use of dispersants in coastal and marine waters of the state. Each is a combination of dispersant approval/nonapproval scenarios which result in a unique combination of spill management strategies. Each alternative also responds to the issues and concerns in different ways.

Together, these alternatives present a broad range of management alternatives. They were formulated through an analysis process that explored a wide array of dispersant use opportunities. The following alternatives were selected for detailed study:

Alternative NC (No Change)
Alternative A (No Dispersant Use)
Alternative B (Blanket Pre-Approval)
Alternative C (Selected Pre-Approval - preferred)
Alternative D (Selected Pre-Approval)

Tables 1-4 summarize the seasonal dispersant use decisions by alternative. Appendix C (Tables 1-20) compares the seasonal dispersant use subregion to adjacent subregions that might stand to benefit from dispersant use. In each table the 7 resource categories are ranked on a 1-5 basis to provide a comparative analysis between use and non-use dispersant subregions.

5.3.1 Assumptions Common to All Alternatives

For the purpose of analysis four assumptions were considered as common to all alternatives:

1. The natural resource ranking system is treated the same in all alternatives;

2. Dispersants will not be applied in nearshore zones;

3. Dispersants are assumed to be no more or less toxic than oil;

4. Impacts associated with dispersant use are related to the risk of increased exposure of biological resources to the oil;

5.3.2 Alternative NC (No Change)

Alternative NC was developed to continue management of dispersant use under current plans, policies and direction. Alternative NC features post-spill OSC decision flexibility with the current Washington state policy requiring a decision by the

Director of Ecology on a case by case basis. Although dispersants may be used, the underlying policy direction of this alternative is first to contain and mechanically recover as much of the spilled oil as possible from the water surface. Capacity to do this is high; in theory, 600 gallons per minute (GPM) by skimmer vessels (1850 GPM in total). Realistic skimming capacity for Clean Sound Cooperative is on the order of 1,000 to 3,600 gallons per hour.

Each decision would be based on a spill by spill basis with no preapproval authorized. The ARS would serve as a reference point for resource decisions.

5.3.3 Alternative A (No Dispersant Use)

Alternative A is designed to feature mechanical recovery of oil with a no dispersant use option. The expectation is that with up to 60 miles of boom and an increase in skimming capacity, the circumstances under which a larger portion of the oil spilled can be recovered will be extended. The intention in most cleanup operations is to maximize the oil recovered which (1) can be accepted by a refinery for processing and which (2) is high in proportion to the amount of debris and sediment collected. The latter becomes more significant if offshore containment and recovery has not prevented all the oil from stranding. The proportion of an oil slick which can be contained and recovered will possibly be increased by use of permanent boom moorings and mountings, fixed at likely natural collection points for oil, or to protect particularly sensitive resources.

It is generally accepted that mechanical recovery techniques for spilled oil are limited in effectiveness if sea state, accessibility of the spill, response preparedness and training are not optimal. Even when these factors are optimal, for spills above a certain size, mechanical methods are not adequate to recover all the oil. The availability of sufficient mechanical recovery equipment is one limiting factor. For larger oil spills the concurrent requirements of adequate control and communications and the high degree of equipment operator skill and flexibility become important to the operations' success. Generally, mechanical recovery techniques rely on concentrating and containing oil within a given area. This generally is in opposition to the natural tendency of oil to spread, for slicks to fragment into windrows and for many oils to disperse naturally. It is a common misconception that a large oil spill can be fully contained and recovered. Considerably more success can be achieved when the spill occurs in relatively sheltered waters.

In cases where the spill approaches or exceeds ~20,000 t (7 million gallons), which is the maximum size used by the USCG for planning purposes, shoreline oiling is almost inevitable. Cleanup techniques onshore are still not very effective: they can greatly reduce the layer thickness of stranded oil, but even quite intrusive techniques such as hot water washing will often fail to remove all of the oil. Under these circumstances, good arrangements have to be made in advance for retrieving and handling oiled sediments, oiled debris (algae, logs, trash), and, in particular, oiled animals and birds.

Under this alternative no dispersant use regardless of resource values would be authorized.

5.3.4 Alternative B (Blanket Preapproval)

Alternative B (Tables 1-4) is designed to feature blanket preapproval of dispersants in all offshore regions. This alternative features preapproval for dispersant use in all spills that occur in the offshore zones and that may endanger habitats or species previously identified. Decisions to use dispersants are delegated to the OSC after review of physical and operating conditions at the time of the spill. If these conditions are acceptable dispersant use could be implemented. This alternative features offshore cleanup rather than featuring resource values.

Under Alternative B there would be preapproval for all dispersant use subregions and seasons.

5.3.5 Alternative C (Preferred Alternative)

Alternative C was designed to feature protection of the vast pelagic fishery resources. This alternative is a modified extension of the NC Alternative designed to make the current policy practical in its implementation. The proposed (preferred) alternative is designed to allow the On Scene Coordinator the opportunity to use dispersants in certain preapproval geographic regions during certain seasons. The OSC, when authorizing use in a case by case scenario, would also be required to assess a variety of factors to determine whether or not the use of dispersants would result in less environmental damage than would occur using non-chemical spill control and clean-up techniques.

This alternative features summer, fall and winter preapproval of dispersants in subregions along the outer Continental shelf and shelf edge, case-by-case approval along the inner Continental Shelf throughout the year, case-by-case approval in the outer Strait of Juan De Fuca and Haro Strait, and no dispersant use in the inner Strait of Juan De Fuca or Georgia Strait (Tables 1-4).

The following selection criteria were applied to Appendix C, Tables 1-20, to make the dispersant use decisions for Alternative C.

Preapproval

Fish < 9; Birds or Marine Mammals => 3; and/or Sensitive Habitat

Case-By-Case

Fish > 9; Birds or Marine Mammals = 5
Fish = 9; Birds or Marine Mammals => 3; and/or Major Sensitive Habitat
Fish < 9; Any Individual Fish Value => 4; Birds or Marine Mammals => 3; and/or Sensitive Habitat
Fish < 9; Birds and Marine Mammals < 3; and/or Major Sensitive Habitat

No Dispersant Use

Fish > 9; Birds and Marine Mammals =< 4
Fish = 9; Birds or Marine Mammals < 3; and/or Sensitive Habitat

=> means "equal to or greater than"

Due to the continued concern over the use of dispersants, as part of the preferred alternative we have chosen to create a dispersant use support team with the following direction:

(1) It will be coastwise and involve the states of Washington, Oregon, California, the federal government, and British Columbia, and

(2) The team will design a monitoring plan, be trained in this specialized field, direct efficacy testing in field situations, and evaluate study results.

When the team is ready dispersants will be used and evaluated on a spill of opportunity. Alternative C as described in this EIS will serve as Washington State's interim dispersant use policy until the coastwise effort offers a new approach.

The team will be created under the auspices of the States/B.C. Task Force to conduct additional research and develop a consistently applied dispersant use policy for the Pacific Coast.

5.3.6 Alternative D

Alternative D is also designed to protect the fishery resources of the state but also allow additional decision flexibility. This alternative features year around preapproval of dispersants in subregion 110, preapproval is allowed during some times of year in the Juan De Fuca, Georgia, and Haro Straits; Case-By-Case approval is given quite often, and a No Dispersant Use decision results during spring in the Strait of Juan De Fuca and other inland waters (Tables 1-4).

Alternative D would allow dispersant use when Fish and Bird values in the dispersant use subregion are as follows:

<u>Preapproval</u>

Fish Value =< 10; Bird or Marine Mammal => 3; Sensitive Habitat

<u>Case-By-Case</u>

Fish Value => 12; Bird or Marine Mammal Value => 4
Fish Value > 10 but < 12; Bird or Marine Mammal => 3; Major Sensitive Habitat
Fish Value =< 10; Bird or Marine Mammal < 3; Sensitive Habitats

<u>No Dispersant Use</u>

Fish Value => 12; Bird or Marine Mammal < 4
Fish Value > 10 but < 12; Bird or Marine Mammal < 3; Minor Sensitive Habitats

5.4 Comparison of Alternatives

The dispersant use decisions are summarized by alternative in Tables 1-4. The consequences of the proposed alternatives, including their environmental trade-offs, are summarized in Appendix C. The following analysis was used to formulate the alternatives and provide a basis for resource tradeoff decisions.

Seasonal resource and dispersant use tables were prepared for all regions and adjacent subregions that might benefit from offshore dispersant use (Appendix C). For purposes of describing the decision process the spring season in region 2, the Outer Straits of Juan de Fuca, will be explored.

The Analysis of the Resource Situation (ARS) information was organized by season and subregion (Appendix C, Tables 1-20). Table 1 summarizes the spring season in region 2. Biological advantage depended on species ranking, mix and abundance. Finally, dispersant use decisions were determined by the IF/THEN criteria defined for each alternative, as shown above.

CHAPTER 6 - AREAS OF CONTROVERSY AND UNRESOLVED ISSUES

A large number of environmental issues were identified during discussions concerning the use of dispersants. When the NRC (1989) reviewed the environmental concerns related to the impacts on natural resources they found that the environmental consequences related to dispersant use tended to be somewhat less than definitive. The biological impacts associated with the use of dispersants are only generically understood at this point. Much of the disagreement has centered around whether dispersants are more or less toxic than the product being dispersed. For purposes of this EIS the relative toxicity of dispersed and undispersed oil is considered the same.

The research database is frequently not definitive enough to adequately judge specific individual and possible synergistic effects on specific in-situ organisms. Consequently, for purposes of the state's dispersant policy application judgements were based on featuring specific resource values. Each alternative featured a unique mix of resources which will be differently impacted by the dispersant use choice.

One of the state's major concerns is the vast fishery resource in Washington and how do offshore biological effects associated with oil dispersal compare with effects of stranding oil on shoreline habitats, including the intertidal and immediate subtidal habitats. During the winter, spring, and early summer, the marine and estuarine surface waters of the state represent the major nursery area for that entire fishery resource. More that 50% of the species in Washington have some pelagic life phase that puts them at risk. Results concerning acute effects of chemically dispersed oils on organisms and habitats seems to vary and, consequently, makes definitive judgments difficult.

These major concerns governed the dispersant use decisions. Uncertainty about these concerns lead to the selection of Alternative C. The concerns can be grouped into three categories:

1. Where does the oil go when dispersed?
2. How toxic is the dispersed oil?
3. Where are and what resources will be most likely impacted?

1. Where does the oil go when dispersed?

This concern is related to the possible expansion of the surface area of the slicks treated by dispersants.

The major concern of fishery and wildlife agencies is related to the impacts associated with increasing the contact area of toxic oil fractions as dispersed oil moves from a largely surface impacting spill to a well dispersed and deeper phenomena. The acute toxic impact of oil is highest when oil is being dispersed (NRC, 1989). The total volume of the affected area is greatly magnified by this effect and, consequently, greatly increases the fish resources at risk. Organisms near the water surface are exposed to higher concentrations of undispersed oil than are organisms in the water column, particularly in the upper layers, will experience greater short-term exposure to oil components if the oil is dispersed.

When examining the NRC summary documents and their analysis of issues, it is clear there is not enough information to say one way of the other. Theories expressed in these summaries speculate as to whether this increased distribution of dispersed oil from the surface into the upper water column will cause more or less damage due to dispersion and dilution.

NRC summary documents also state that we do not know where and how far dispersed oil will go. Is there enough information on how turbulent diffusion, surface circulation, and wave motion affect dispersed oil distribution as a function of depth, time, and volume of spilled and treated oil? The NRC (1989) concludes that although circulation phenomena have been observed qualitatively, predictive theories are not yet dependable. See Appendix D for a description of factors which affect detergent effectiveness.

Is there enough understanding of the mechanics of dispersed oil resurfacing and spreading in order to evaluate impacts of oil on fish larva, marine mammals, and birds? Partial resurfacing of dispersed oil, after agitation ceases, occurs under lab conditions. There is disagreement about its occurrence in practical situations because of little quantitative information. However, resurfacing of dispersed oil may be less likely than that of untreated oil because of the smaller droplet size (NRC, 1989).

2. How toxic is the dispersant/dispersed oil?

How toxic are dispersants and chemically dispersed oil, to marine plants and animals in laboratory studies? The acute lethal toxicity of most dispersants currently considered for use is low when compared to the constituents and fractions of crude oils and refined products. It is unlikely, based on concentrations of dispersants that would result from spraying in marine waters at common rates, that dispersants would contribute significantly to lethal or sublethal toxicities (NRC, 1989). These conclusions are, however, based on laboratory tests only.

Is there enough data on the toxic effects of both untreated and dispersed oil on surface dwelling organisms affected to determine the difference between dispersed and non-treated oil? The NRC, 1989, concluded that acute toxicity of chemically dispersed oils is generally similar to that portion of the oil in the water column alone. Based on lab studies, acute lethal toxicity of chemically dispersed oil for most species resides not in the dispersant, but primarily in the oil droplets and the low molecular weight and dissolved, aromatic, and aliphatic fractions of the oil.

3. Are there greater adverse ecological effects from dispersed oil on the marine life in shallow water environments and other habitats having restricted water exchange?

In shallow water with poor circulation, and in protected bays and inlets, the acute biological effects on some organisms and habitats from high concentrations of dispersed oils may be greater that the effects of untreated oils (NRC, 1989). Unless there was the appropriate time for oil to disperse no dispersant would be used to protect nearshore habitats. A minimum surface area of 200 sq km and a distance of greater than 3 miles to shoreside areas was selected as the potential approval/nonapproval subregion size. A subregion that met these criteria was considered for dispersant use.

Figure 1 Decision Process for Selection of Dispersant use Pre-approval (Alternative C)

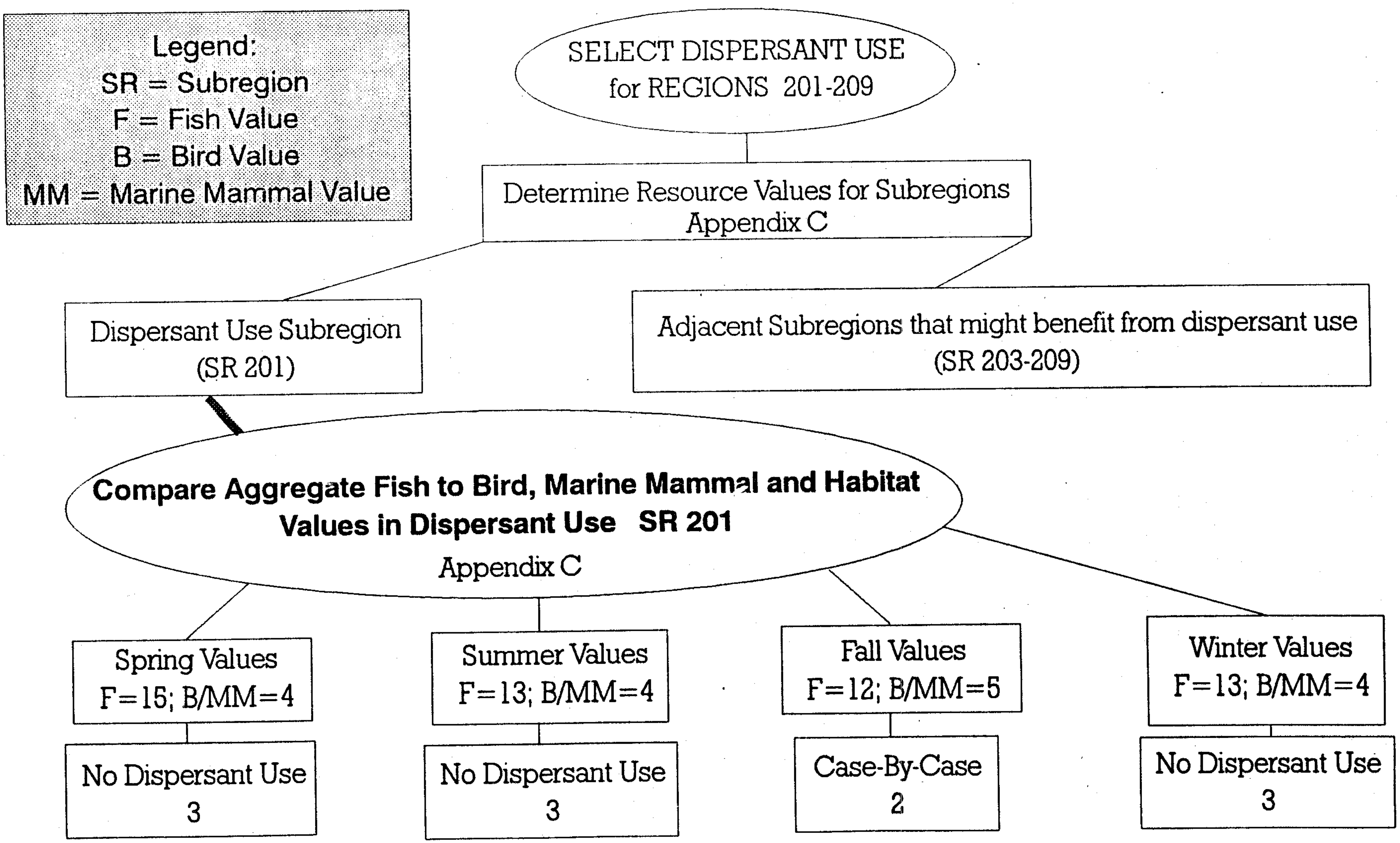

TABLE 1. SPRING DISPERSANT PREAPPROVAL COMPARISON BY ALTERNATIVE

SUBREGIONAL NAME	SUBREGION	Alternative NC	Alternative A	Alternative B	Alternative C	Alternative D
Inner Shelf	109	2	3	1	2	2
Outer Shelf	110	2	3	1	2	1
Shelf Edge	111	2	3	1	2	1
Continental Slope	112	2	3	1	2	2
Outer Strait of Juan De Fuca	201	2	3	1	3	3
Inner Strait of Juan De Fuca	301	2	3	1	3	3
Eastern Georgia Strait	608	2	3	1	3	3
Western Georgia Strait	703	2	3	1	3	3
Northern Haro Strait	801	2	3	1	2	3
Southern Haro Strait	802	2	3	1	2	3

DISPERSANT USE CATEGORY

1 - PREAPPROVAL FOR DISPERSANT
2 - CASE BY CASE DISPERSANT USE APPROVAL
3 - NO DISPERSANT USE

SPRING MONTHS: March thru May

TABLE 2. SUMMER DISPERSANT PREAPPROVAL COMPARISON BY ALTERNATIVE

SUBREGION	SUBREGIONAL NAME	Alternative NC	Alternative A	Alternative B	Alternative C	Alternative D
109	Inner Shelf	2	3	1	2	3
110	Outer Shelf	2	3	1	1	1
111	Shelf Edge	2	3	1	1	2
112	Continental Slope	2	3	1	2	2
201	Outer Strait of Juan De Fuca	2	3	1	3	2
301	Inner Strait of Juan De Fuca	2	3	1	3	1
608	Eastern Georgia Strait	2	3	1	3	1
703	Western Georgia Strait	2	3	1	3	2
801	Northern Haro Strait	2	3	1	3	2
802	Southern Haro Strait	2	3	1	3	2

DISPERSANT USE CATEGORY

1 - PREAPPROVAL FOR DISPERSANT
2 - CASE BY CASE DISPERSANT USE APPROVAL
3 - NO DISPERSANT USE

SUMMER MONTHS: June thru August

TABLE 3. FALL DISPERSANT PREAPPROVAL COMPARISON BY ALTERNATIVE

SUBREGION	SUBREGIONAL NAME	Alternative NC	Alternative A	Alternative B	Alternative C	Alternative D
109	Inner Shelf	2	3	1	2	2
110	Outer Shelf	2	3	1	1	1
111	Shelf Edge	2	3	1	1	2
112	Continental Slope	2	3	1	2	2
201	Outer Strait of Juan De Fuca	2	3	1	2	1
301	Inner Strait of Juan De Fuca	2	3	1	3	1
608	Eastern Georgia Strait	2	3	1	3	1
703	Western Georgia Strait	2	3	1	3	2
801	Northern Haro Strait	2	3	1	2	1
802	Southern Haro Strait	2	3	1	2	2

DISPERSANT USE CATEGORY

1 - PREAPPROVAL FOR DISPERSANT
2 - CASE BY CASE DISPERSANT USE APPROVAL
3 - NO DISPERSANT USE

FALL MONTHS: September thru November

TABLE 4. WINTER DISPERSANT PREAPPROVAL COMPARISON BY ALTERNATIVE

SUBREGION	SUBREGIONAL NAME	Alternative NC	Alternative A	Alternative B	Alternative C	Alternative D
109	Inner Shelf	2	3	1	2	2
110	Outer Shelf	2	3	1	1	1
111	Shelf Edge	2	3	1	1	2
112	Continental Slope	2	3	1	2	2
201	Outer Strait of Juan De Fuca	2	3	1	3	1
301	Inner Strait of Juan De Fuca	2	3	1	3	2
608	Eastern Georgia Strait	2	3	1	3	2
703	Western Georgia Strait	2	3	1	3	2
801	Northern Haro Strait	2	3	1	3	1
802	Southern Haro Strait	2	3	1	3	2

DISPERSANT USE CATEGORY

1 - PREAPPROVAL FOR DISPERSANT
2 - CASE BY CASE DISPERSANT USE APPROVAL
3 - NO DISPERSANT USE

WINTER MONTHS: December thru February

TABLE 5. SUMMARY OF PREFERRED ALTERNATIVE SEASONAL DISPERSANT USE DECISIONS

SUBREGION	SUBREGIONAL NAME	SPRING	SUMMER	FALL	WINTER
109	Inner Shelf	2	2	2	2
110	Outer Shelf	2	1	1	1
111	Shelf Edge	2	1	1	1
112	Continental Slope	2	2	2	2
201	Outer Strait of Juan De Fuca	3	3	2	3
301	Inner Strait of Juan De Fuca	3	3	3	3
608	Eastern Georgia Strait	3	3	3	3
703	Western Georgia Strait	3	3	3	3
801	Northern Haro Strait	2	3	2	3
802	Southern Haro Strait	2	3	2	3

DISPERSANT USE CATEGORY

1 - PREAPPROVAL FOR DISPERSANT
2 - CASE BY CASE DISPERSANT USE APPROVAL
3 - NO DISPERSANT USE

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APPENDIX B
AFFECTED ENVIRONMENT

APPENDIX B

AFFECTED ENVIRONMENT

Introduction

This appendix provides objective factual information about the physical environment of the open coast of Washington, the western Strait of Juan de Fuca to Port Angeles, and the eastern Strait of Juan de Fuca. Much more detailed documents already exist from which some of this material derives, such as the Washington Department of Ecology Coastal Zone Atlas and the Oregon and Washington Atlas of Sensitivity of Coastal Environments and Wildlife to Spilled Oil. Refer to these sources for local details.

Open Coastal Waters

1. Geologic Setting

A brief discussion of the general coastal lithology and structure of each geographic region is included so that physical characteristics and processes of the coastline can be better understood.

The geology and physical features of western Washington reflect collision between the Farallon plate, which forms the seafloor off the coast of the Pacific Northwest, and the continental North American plate, including Washington, Oregon, and the continental shelf. These plates collide offshore near the base of the continental shelf, where the denser plate, Farallon, is subducted under and eventually melts beneath the less-dense North American plate. Melting drives volcanic activity inland in the overriding plate; the Cascade Range expresses this process. Subduction of the Farallon plate off the coast of Washington and Oregon, with attendant Cascade volcanism, has been going on for more than 50 million years (MY) (Duncan and McElwee, 1984). Collision and subduction of these plates resulted in folding and uplift of deposits along the coast, and caused the Coast Range of Oregon and southern Washington to rise. Sometimes massive features of the Farallon plate, possibly seamounts, are not subducted but are broken off and accreted to the continental margin instead, with great deformation to the surrounding deposits of the North American plate. The rocks of Washington's Olympic Peninsula were added to the continent in this manner between about 30 MY and 12 MY ago (Johnson, Brandon and Stewart, 1984).

As collision and subduction built the Cascade and Coast Range highlands, a broad lowland trough was formed between them: the Puget Lowland. The Puget Lowland was scoured and filled during repeated Pleistocene glaciations. At least three times thick ice sheets advancing from the Canadian Cordillera have reached Puget Sound. They leave behind a complex record of sediments and landforms (Haase, 1987; Thorson, 1980; Bretz, 1913). Ice covered and carved the Strait of Juan de Fuca as well as Puget Sound; regional drainage was along the Chehalis River of south-western Washington. Global sea level during glaciation was more than 100 meters lower than present; relict glacial outwash from the engorged Chehalis River can be found at the continental shelf's edge off Grays Harbor. Lesser glaciers occupied the Cascade and Coast Ranges, contributing sediment to the lowland and offshore as well.

Since the retreat of the last Puget Lowland ice sheet about 12,500 years ago (Thorson, 1980) and accompanied by a rapid rise in sea level to near-present conditions, the processes of uplift, volcanism, and erosion related to collision between the Farallon and North American plates have continued. Some authors consider the subduction rate to have slowed considerably in the past several million years (Duncan and McElwee, 1984).

In addition, human activity in the past 100 years has changed patterns of erosion and deposition in many parts of Washington, especially along the coastlines.

2. Geological Characteristics of the Outer Washington Coast

The outer coast of Washington can be split into three generalized geomorphic sectors: south, central, and north.

A) South Sector

From the mouth of the Columbia River to the Copalis River, the coast consists of broad, sandy beaches fronting beach and dune ridges, backed by a gently rolling plain with two large estuaries, Grays Harbor and Willapa Bay. These bays are the drowned channels of glacial-age rivers impounded behind spit-like barrier beaches formed of Columbia River sand. The second longest beach in the United States, aptly-named Long Beach, runs for more than 30 km between Willapa Bay and the Columbia River. Net shore drift is dominantly northward, although local reversals exist such as north of the entrance to Grays Harbor. Drift cells tend to be large, often longer than 10 km along the linear beaches of the southern coastline. Sand accumulation against jetties built to stabilize this channel record little net littoral drift.

Accretion along this extensive beach system is fed by sand carried from the mouth of the Columbia, sediments of the Chehalis and Willapa Rivers depositing mainly within their estuaries (Komar, 1985). With the construction of large dams on the Columbia this century, it is possible this progradation regime may stabilize or change to one of erosion. At present, severe erosion is taking place at Cape Shoalwater, over 3000 m retreat in the past 90 years, but this is thought to be due to channel migration. Migrations of the northern tip of the Long Beach Peninsula up to 2000 m have also been recorded (Terich and Schwartz, 1981). Accretion rates diminish and the beaches grow narrower north of Grays Harbor where the amount of Columbia River sediments decrease.

B) Central Sector

The coast from the Copalis River to the Hoh River is characterized by sand and gravel beaches of moderate width, backed by sea-cliffs (average height about 30 m). The sea-cliffs are Tertiary continental and marine sediments overlain with Quaternary glacial deposits. Elevated marine terraces record Pleistocene uplift of up to 40 m. Beach material is supplied by mass-wasting of the cliffs and from several rivers entering the Pacific along this stretch of coastline. Transport and accretion of Columbia River sediment is minimal. Large drift cells with northward drift predominate, as evidenced by the development of a bar to the north across the mouth of the Quinault River. However, the accumulation rates are much lower than the south sector.

C) North Sector

From the Hoh River northward to Cape Flattery, shorelines consist of steep cliffs, pocket beaches, and abrasion platforms cut into Tertiary sandstone and conglomerates interfingered with generally basaltic volcanics, blanketed by Quaternary glacial sediments. Major promontories are formed by the more-resistant volcanic formations through differential erosion. Sea stacks and cliffs over 60 m in height are common. Beaches (other than small isolated pocket beaches) are rare. The occasional sediments that accumulate on the abrasion platforms consist of gravel and cobbles. The sediments of the pocket beaches are dominantly sand and gravel. As for the rest of the outer Washington coast, net drift is to the north. Although drift cells in the north sector are small, 1-5 km in length, and local southward reversals are common. No net drift is found along the wave-cut platforms and steep cliffs surrounding Cape Flattery.

3. Bathymetry

The morphology of the ocean floor off the Washington coast is characterized by a relatively narrow shelf and a steep slope where the Juan de Fuca and Pacific oceanic plates meet the North American plate. The shelf (depths to approximately 200 m) varies in width from 15 km off Cape Blanco in southern Oregon, to 75 km off Cape Flattery, Washington, with an average of about 100 km width off Grays Harbor (Kulm *et al.*, 1984). From the Columbia River north to the Strait of Juan de Fuca, the shelf and slope are cut by deep canyons. A bathymetric map of the Washington shelf (to 200 m) and the entire offshore area for the Washington coast is shown in Figure A-2.

4 . Meteorology

The climate of the Pacific Northwest coast varies seasonally with the migrations of two dominant pressure systems. The Aleutian Low dominates the region's weather from late fall to early spring. It is characterized by cyclonic (counter-clockwise) winds, and numerous frontal systems. This means mostly wet, cloudy days and moderate temperatures for the Pacific Northwest west of the Cascade range (Figure A-3). Occasionally an outbreak of Arctic air from the northeast will bring cold, dry and clear weather for three or four days.

The Aleutian Low is replaced by the North Pacific High from late Spring to early Fall. The North Pacific High is accompanied by anti-cyclonic, clockwise winds and a more stable air mass. There is generally less rain and more favorable weather during this period, although local effects, such as diurnal sea breezes and fogs are important local weather considerations.

Storms with gale force winds and precipitation are most common during the winter months. During the summer, skies can be clear or hazy, but there are few strong winds and little precipitation. Temperature, frequency of strong winds, and precipitation follow relatively smooth curves, with maxima in wind speeds and precipitation and minima of temperature occurring in December and January, while maxima in temperature and minima in wind speeds and precipitation occurring in the period June to August (Figures A-4 & A-5).

The local weather patterns are determined by the prevailing conditions and the morphology of the coastal zone. The outer coast of Washington is exposed to the weather systems dominating over the Pacific. They vary seasonally along with the weather systems. Winds are generally westerly, tending to be from the southwest in the period October to March, and from the northwest April to September. The peak winds (Table A-1), occur during the winter months (December to February) when 5.5-6.3% of reported wind speeds off the coast of the Columbia River are greater than 34 knots. In the spring (March to April) and fall (October to November), this wind speed is exceeded 2.6-4.8% of the time; for the summer (May to September), 0-0.5% of recorded wind speeds exceed 34 knots.

Fog is a prevalent feature of the local weather. Heavy fog occurs most often in the summer months from July through October. Its occurrence for the open coast is displayed in Table A-2. At Tatoosh Island heavy fog is present on more than half the days during August.

5. Currents, Tides, Waves and Hydrographic Profiles

The tides, currents and hydrography of the open coastal areas of Washington are directly affected by the regional oceanic and atmospheric processes of the northern Pacific Ocean. The coastal region is influenced by generally weak (5-30 cm/sec) and poorly defined ocean currents and seasonal variations in atmospheric pressure systems of the north Pacific (Barnes *et al.*, 1972). The freshwater outflow of the Columbia River has a profound effect on the surface water properties along both the Washington and Oregon coasts.

The stationary atmospheric pressure system of the North Pacific High dominates the weather patterns during the summer, producing generally calm weather and light winds (predominantly from the northwest and north) (Barnes *et al.*, 1972; Neal, 1972). By November, the high pressure cell has weakened and migrated southward and the Aleutian Low begins to dominate the coastal region (Barnes *et al.*, 1972). The Aleutian Low is a system of migratory lows that sweep onshore from the west, producing considerable day-to-day wind and wave variation. These low pressure systems produce severe winter storms with gale force winds, high seas and large waves mostly from the southwest, and can last for several days. The southerly winds prevail from October through April (Neal, 1972). Northerly winds of lesser force prevail from May through September (Barnes *et al.*, 1972).

A) Currents

The regional ocean current affecting the coast is the eastward flowing North Pacific West Wind Drift ocean current, which separates more than 300 miles off the Washington and Oregon coast. The southward flowing branch is the California Current. The California current originates farther north during the summer than in the winter. Inshore of the California Current is the northward flowing Davidson Current which has a surface speed of a few tens of centimeters per second. This current is generally confined to the area over the continental slope. During autumn and winter the Davidson current develops a surface expression which abates in the late spring. The current is probably permanent in deeper waters (Swift *et al.*, 1972).

Two distinct net surface flow trends are established for four- to five month periods each year during the winter and summer months. Relatively short transition periods, typified by highly variable wind and current conditions, occur in the spring and autumn and separate the periods of distinct net flow conditions (Barnes *et al.*, 1972) The seasonal variations in the winds affect the speed and direction of the alongshore drift and surface water currents over the continental shelf. These currents tend to follow the predominant seasonal wind patterns; north in the winter and south in the summer. Observed surface current flows are approximately parallel to the coast (Swift *et al.*, 1972). Barnes *et al.*, (1972) cite several surface current studies in which the average southerly set of the current during the spring and summer is 5 cm/sec and reaching a maximum of nearly 20 cm/sec. Another study determined the south drift off of the northern Washington coast to be 3.5-7 km/day during the summer. The northerly surface flow during the winter generally ranges between 10-20 cm/sec (Barnes *et al.*, 1972).

Winter southerly winds move the surface waters northward and toward shore. Due to the Coriolis Effect, surface ocean currents are deflected to the right of the surface wind direction in the northern hemisphere. Thus southerly winter winds cause the surface waters over the continental shelf to be deflected landward, flow onshore and pile-up along the coast. This build-up of water causes a northward flowing nearshore current at the surface with an offshore flowing component along the sea bed. The resultant downwelling forces surface water downward as it approaches the coast and breaks down any water column stratification (Swift *et al.*, 1972).

The surface circulation pattern is reversed during the summer months when the winds are blowing from the north. The northern summer winds produce an offshore movement of the surface waters to the south and west and promote upwelling. The Coriolis effect forces the surface water seaward forming a depression of the water surface near the coast. This circulation of the surface waters away from the coast causes upwelling of denser, colder, more stratified bottom water along the coast to replace the southward flowing surface water that has moved offshore.

Bottom currents in water depths of 40-90 meters along the central continental shelf off Washington flow predominantly northward during both the winter and summer (Swift *et al.*, 1972). These bottom currents flow parallel to the shelf contours or have a slight offshore component. Several bottom current studies have demonstrated that the predominant drift in water depths greater than 40 meters is northward at an average rate of 1-2 km/day. Maximum speeds of over 3 km/day occur usually during the winter months (Barnes *et al.*, 1972). Sea bottom "drifters" released near the mouth of the Columbia River at these depths have entered the Strait of Juan de Fuca (Swift *et al.*, 1972).

On the inner continental shelf, in water depths less than 40 meters, there is a net onshore drift of bottom currents, as shoaling waves, wave driven currents, tidal currents and upwelling have an increasingly important affect on the bottom currents (Swift *et al.*, 1972; Barnes *et al.*, 1972). In water of 40-50 meters waves begin to interact with the sea bottom. Drifters released in these water depths quickly washed ashore due to waves and upwelling. The shoreward bottom currents have been measured at 0.7-2.5 km/day. The shoreward set of bottom currents quickly follows the onset of northerly winds which cause the offshore movement of surface waters and coastal upwelling of bottom water.

Bottom currents adjacent to the mouth of the Columbia River have a more complex and less direct flow pattern. Drifters released in water depths of less than 40 meters and within 10 km of the river mouth move predominantly toward the mouth at typically 1.4 km/day. Bottom currents moving north from south of the mouth are deflected into the river estuary on the south side channel. Some wash ashore on Clatsop Spit, the landward extent of effective wave penetration from the open ocean. The deflected bottom currents move up the Columbia River, across to the north side of the river and back out to sea. The current then moves northward so some drifters again wash ashore on the north beach. The four kilometer section of beach north of the north jetty and Clatsop Spit on the south side of the channel are both areas of rapid sedimentation. There is also a minor intermittent southward component of the bottom flow south from the mouth (Barnes *et al.*, 1972). A fraction of the sediments from the Columbia are supplied to the beaches at Clatsop Planes south of the river (Bird and Schwartz, 1985).

B) Tides and Waves

The tides along the coast are of the mixed semidiurnal type where two high tides and two low tides of unequal heights occur during each day (Bird and Schwartz, 1985; Thomson, 1981). The tidal range along the Washington coast averages 4 meters during spring tides and 2 meters during neap tides.

Both the coast of Washington and Oregon are characterized by high wave energy averaging 2 meters during the summer months and 3-4 meters during the winter (Bird and Schwartz, 1985). The waves impinging on the Washington coast are predominantly southwest and west-by-southwest. Northwesterly waves develop during storms. The maximum wave heights along the Washington coast are over 9 meters.

The percentage of large wave heights follows the wind data. Waves larger than 10 feet are reported about a third of the time in the period December to March. Approximately 10% of the reported wave heights are over 10 feet in April and May, while October and November report these large waves almost 20% of the time. During the summer, from June through September, the frequencies range from 1.4-4.7%.

C) Littoral Drift

The net shore drift along the Washington coast is mainly to the north, though local flow reversals occur (Bird and Schwartz, 1985) (Figure A-6). They are generally found in the "wave shadow" of headlands, where waves are refracted around islands and sea stacks near the coast, and where orientation of the coastline varies considerably from that of the general coastal trend. At Cape Disappointment there is a short reversal toward the north jetty of the Columbia River. From Cape Disappointment northward for 40 km along the Long Beach Peninsula to the south entrance to Willapa Bay, the net shore-drift is to the north. At the south side entrance, the flow bends around the spit at Leadbetter Point and into the baymouth. On the inner north side of the entrance the net flow is also into the baymouth. From Cape Shoalwater at the north of the bay entrance, the net transport is again northward to the south jetty at Point Chehalis at the south side of the inlet to Grays Harbor. For a short distance north of the inlet there is a southward reversal. This reversal and the reversal on the north side of the Columbia River are due to wave refraction around shallow water deposits (Schwartz *et al.*, 1985).

The coastline further north is of a rocky, more irregular nature and breaks the shore-drift into numerous drift cells. The net shore-drift in these discrete cells is predominantly to the north. There are, however, six reversals with a net southern drift due to refraction around headlands, sea stacks and arches. The reversals occur at: Taylor Point, LaPush north of the Quileute River, north of Cape Johnson, north of Sands Point, north of Cape Alava, and north of Point of Arches (Schwartz *et al.*, 1985).

D) Columbia River Hydrography

The fresh water outflow from the Columbia River has a significant influence on the surface water properties along the coast. The freshwater runoff from the Columbia River enters the ocean and mixes with marine waters of the continental shelf, diluting the surface water and causing a low salinity layer that is traceable over large distances. An estimated average of 6.0 x 10^6 m^3/day mixes with ambient seawater.

The average discharge from the Columbia is 7300 m^3/s . The maximum flow of the river occurs during May, June and July due to snow melt at its distant headwaters. Dams along the river limit the maximum discharge to 17,000 m^3/s; the minimum discharge is maintained above 4250 m^3/s (Neal, 1972). In the summer the Columbia River accounts for 90% of the fresh water entering the ocean between the Strait of Juan de Fuca and San Francisco Bay. In the winter it accounts for only about 60% of the fresh water discharge into the ocean due to an increase in discharge from smaller coastal rivers from seasonal increase in precipitation.

The definition of the Columbia River plume in marine waters, using salinity measurements, is detectable for several hundred kilometers at sea. The direction and extent of the plume is dependent upon direction of seasonal wind-driven surface currents. During the summer, the southward flowing surface currents and offshore drift associated with coastal upwelling opposes the northward Coriolis deflection of the low-density, diluted river plume in the coastal waters, forcing the plume in a broad southwesterly direction. The summer plume can extend 300-400 km seaward and 500 km southwest of the mouth during the summer months (Barnes *et al.*, 1972; Swift *et al.*, 1972).

During the winter months the prevailing northward surface current, the onshore pile-up of water and the density driven freshwater plume of the Columbia River are all in the same direction. They drive the low salinity waters generally northward and confine them close to the Washington coast. During the winter the Columbia River plume extends seaward 50-100 km and from 100 km south of the mouth northward to the Strait of Juan de Fuca. The Columbia River plume during the winter months is less distinct than during the summer. In the winter the low salinity zone is confined next to the coast and increased seasonal freshwater from other coastal rivers prevents an increase in the surface water salinity along the Washington coast to the Strait of Juan de Fuca.

The freshwater discharge from the coastal rivers can be high during storms, especially from the rivers that feed Willapa Bay and Grays Harbor. Following major storms along the coast there is a seaward bulge in the freshwater plumes from the mouths of these coastal bays and rivers. There is a fresh water bulge off the Columbia at all times of the year. Water properties change slowly once the plume moves offshore from the mouth of the river. During periods of highest discharge, surface salinity can be 20 ppt (parts per thousand) and they are 28-30 ppt during minimum discharge. The surface salinity of ambient seawater in this region is considered to be 32.5 ppt.

Particularly near the mouth, the depth of significant dilution is approximately 20 m; lesser dilution reaches 40 m. The plume maintains this 40 m depth of mixing over most of its extent.

As the plume extends seaward, it gradually increases in salinity and spreads laterally as ambient seawater is mixed into the plume. Mixing in the plume occurs mainly by upward entrainment of a more saline, denser lower layer of seawater. Motions of the surface waters have little effect on the waters below the dilute surface layer. As the plume becomes more saline, further incremental increase in salinity occurs more slowly. For these reasons the Columbia River effluent can be traced over great distances. The plume has a distinct boundary near its mouth, especially during times of high runoff, but at the plume's distal limits the actual boundary is always poorly defined.

6 . Shoreline Morphology, Characteristics and Environmental Conditions

The outer coast of Washington consists of broad, sandy beaches in the south, a transitional zone of beaches backed by cliffs in the center, and steep rocky headlands with isolated pocket beaches in the north. Man-made structures are not common. Coastal features and the processes governing their morphology are discussed below.

A) Rocky Shorelines

Usually composed of Tertiary volcanics and plunging straight into the ocean, exposed steep cliffs and headlands are common in the north sector. Similar cliffs are typically found on the sea stacks and small islands present along the northern coast, and in a few locations on the central coast as well, but are limited in the southern sector. These features are frequently exposed to high waves and are undergoing active erosion. Using sea stacks, Rau (1973) has calculated a coastal retreat rate of approximately 100 m per 100 years along the central and northern Washington coast. Nearshore sediment transport past headland features is limited, eroded material usually accumulating as pocket beaches between successive headlands. Drift cells of the north coast are usually bounded by headland promontories.

Irregular bedrock terraces near sea level, called "wave-cut abrasion platforms," are pocked with numerous tide-pools and are present along much of the north sector. They may be backed by steep cliffs or low bluffs or surround offshore islands. Wave activity is high in these environments and accounts for the "sawed-off" shape of the platforms. Sediment transport occurs along wave-cut platforms; accumulation is usually limited to cobbles and coarse gravel near the backing highlands although in some localities coarse sand and gravel beaches can be found. Sheltered rocky headlands are not a significant feature along the outer coast of Washington.

B) Sediment Shorelines

Pocket or bayhead beaches from a few hundred meters to several kilometers in length are the predominant beach type along the northern coast. These beaches form in the relatively calm, moderate-to-high energy environments between promontories and accumulate sediments eroded from the surrounding headlands. Most of the pocket beaches along the Washington outer coast consist of mixed sand and gravel or coarse gravel, reflecting erosion of the regional glacial cover. Beaches tend to be coarser nearer the headlands and finer in the middle reaches, although such distribution is by no means uniform. Sediment input from more distant sources is minimal; the deposits within a given pocket beach tend to remain there. Overall shore drift along the northern coast is northward but within any given pocket beach the situation is generally more confused, some building southward, some northward.

Spits and bars can be found along the outer coast. They are narrow ridges of sand and gravel extending from the shore into deeper water and form where sandy sediment from a plentiful source, such as a river, is transported by nearshore currents to deeper water, where the currents slow and the sediments then deposit. Their direction of growth indicates local long-term net shore drift (Jacobsen and Schwartz, 1981). Along the outer Washington coast spits form at the mouths of the lesser rivers (the Chehalis and Willapa Rivers deposit mainly within Grays Harbor and Willapa Bay, respectively). These spits are short and straight, usually less than 1-2 km in length. In a few locations such as the Queets River or within the large estuaries spits may be accompanied by surrounding tidal flats.

Tombolos are spits which connect an island to the adjacent shore. They are not common along the outer coast of Washington although an example can be found at Cape Alava (Tskawahyah Island). A tombolo is made of sand and gravel transported from the neighboring beach or eroded from the island or both; their shape depends on local conditions. In some cases spits may form from both sides of the island to the shore, creating a double tombolo. Between the two spits there is a shallow lagoon or tide flat.

Cuspate forelands are not found along the outer coast. They do not commonly develop along linear beach fronts or rocky shorelines.

Barrier beaches are wide linear accumulations of sand formed along the coastline, often with extensive landward dune development. The coast from the Columbia to the Copalis River is a series of hard-packed fine sand beaches and dunes. The sand was transported northward through shore drift from the Columbia River. The striking linear nature of the southern beaches attests to long-term uniform sediment supply and shore-drift conditions. However, the effect on these beaches of diminished sand supply due to modern dams along the Columbia is uncertain (Terich and Schwartz, 1981).

Deltas form where rivers entering open water deposit sediment faster than it can be removed through shore drift or other marine processes. They are not found along the outer coast; in a high-energy open ocean environment sediments are generally removed as fast as they can be deposited. Deltas are found within Grays Harbor and Willapa Bay estuaries, however, and generally resemble tide flats there. These will be discussed with tide flats in the following subsection.

Tide flats and salt marshes develop in protected waters where there is low energy and a supply of sediments, often near river mouths. Fine sediment accumulates in flats at intertidal elevations while marsh plants often grow in surrounding areas just above the high tide level, cut by branching, changing tidal channels. Along the outer coast these conditions are found in Grays Harbor and Willapa Bay, as well as in the estuary of the Columbia River. Extensive tide flats and marsh development can be found at these sites. The deltas of the Chehalis and Willapa Rivers, within Grays Harbor and Willapa Bay, respectively, also have tide flats. Small tide flats and salt marshes are found inside the mouths of most of the lesser rivers of the outer coast; Mukkaw Bay just south of Cape Flattery also shows salt marsh development.

C) Man-made Structures

Because of low population, significant man-made structures are not common on the outer coast. There are two large jetties at the entrance to Grays Harbor; sediment accumulation along them indicates little net shore drift at this location (Schwartz *et al.*, 1985). Another large jetty, south of Cape Disappointment, helps to stabilize the mouth of the Columbia River. Riprap and other types of sea wall are very rare. Extensive harbor development is found within the two great estuary bays and small marina complexes are present at La Push and Ilwaco.

7. Bottom Sediments

Generalized continental shelf sediments off the outer coast of Washington are shown in Figure A-1 (after Roberts, 1979). Sand is found along the inner shelf while coarse silt from the Columbia River covers most of the outer shelf area (Gross *et al.*, 1967; Nittrouer *et al.*, 1979). During glaciations the continental shelf was exposed through lowered sea level; coarser glacial deposits and outwash accumulated during these times. The Chehalis River drained the Puget Sound ice sheet and relict coarse glacial outwash can be found at the edge of the continental shelf along the path of this stream. Coarser deposits are also present off the Strait of Juan de Fuca where the northern ice lobe terminated. Post-glacial silt from the Columbia has buried these glacial sediments along much of the shelf.

The Columbia River supplies nearly all of the sediment to this section of continental shelf; Olympic Mountain and Coast Range contributions are minimal (Scheidegger, *et al.*, 1984). Investigations of the continental shelf off the coast of Washington have indicated that shelf sediments to 200 m depth may be remobilized during the largest storms. However, under ordinary conditions, only those sediments above 40-50 m depth are mobile. In general, the nearshore sands are trapped near the coast as the bedload of wave-driven onshore currents. Silts may be carried further offshore as suspended load. Most shelf sediment transport appears to occur during a few large storms each year when silt and fine sand can be carried as suspended load (Smith and Hopkins, 1972).

WESTERN STRAIT OF JUAN DE FUCA

1. Geological Setting

The Strait of Juan de Fuca was formed when successive Pleistocene ice sheets advancing from highlands in Canada scoured and deepened the lower reaches of an earlier Fraser River. This river had cut through uplifted and accreted marine and volcanic sediments along the coast prior to glaciation, much as the modern Columbia River has cut through the Coast Range of Oregon and Washington. Erosion by at least three Pleistocene ice sheets has given the Strait of Juan de Fuca the "U"-shaped cross section typical of glaciated valleys.

2. Geological Characteristics

The western Strait of Juan de Fuca (extending from Neah Bay to Port Angeles) can be divided by geology and geomorphology into a western and an eastern sector, with the division at Freshwater Bay. Headlands and cliffs in the western sector are of folded and faulted Tertiary volcanic and sedimentary lithologies with an irregular, thin cover of Pleistocene glacial deposits. In the east glacial drift predominates and exposures of Tertiary bedrock are rare. The coastline to the west consists of alternating stretches of exposed rocky headlands, wave-cut terraces, and gravel or sand and gravel beaches, while typically to the east sand and gravel beaches backed by 50 m high cliffs of glacial and non-glacial sediments are found. Erosion of these cliffs supplies most of the beach sediment and can occur at rates greater than 3 m per 10 years (Anderson, *et al.*, 1977).

Very large spits have developed in the eastern sector such as Ediz Hook and Dungeness Spit. Net drift is predominantly eastward, well shown by spit development. However, local westward reversals are common just to the east of headlands, within semi-protected bays. Drift cells vary widely in size. Sediment supply to Ediz Hook has been greatly reduced since damming of the Elwha River, the major drainage for the central Olympic Mountains; subsequent erosion of the spit has been countered through extensive foreshore revetment and periodic beach nourishment.

3. Bathymetry

The channel of the Strait of Juan de Fuca is morphologically divided east and west of a line from the Gordan River and Pillar Point. To the east the bottom is gently sloping, with a U-shaped cross-channel profile, a result of recent glaciation. A large terminal moraine, the Victoria-Green Point sill (south of Victoria), marks the furthest advance of an ancient ice sheet. West of the line to Cape Flattery the channel is V-shaped, resembling a mature river valley. West of Cape Flattery the channel turns southwest. The depth of the channel decreases gradually from west to east. From a depth of 250 m at mid-channel near the entrance it decreases to 180 m, 70 km east of Cape Flattery. At the Victoria-Green Point sill the channel is only 55 m deep.

4 . Meteorology

The weather over the inland waters is shaped largely by the mountains which serve as barriers to the eastward and westward movement of air. The Strait of Juan de Fuca and the Cowlitz and Chehalis River valleys serve as the inlets and outlets for the air streams that move north and south through the Puget Sound Basin. Winds in the Strait at Port Angeles are predominantly westerly. This differs from the trend in the Puget Sound region as a whole. These winds also exhibit a large peak in frequency of strong winds during the summer. This distinctive feature is a diurnal event, with westerly winds usually becoming strong around noon and lasting until midnight. Neither of the two stations to the east of Port Angeles in the vicinity of the eastern Strait and the Strait of Georgia, in Bellingham and Whidbey Island, show comparable effects.

The eastern and western Strait are subject to strong winds during the winter months. Strong winds at Port Angeles can come from any direction with the exception of due south. The prevailing north winds during the winter months appear to diverge west and east at Port Angeles. During the spring and summer the prevailing winds become westerly through the western Strait and east to northeasterly through the eastern Strait and the southern Strait of Georgia. One local wind pattern of note is the "Ediz Hook Eddy," a counter-clockwise wind pattern that develops off of Port Angeles (Lilly, 1983). It appears when a low develops off the Washington coast and there is an increase in the easterly winds.

Fog is a prevalent feature of the local weather. Heavy fog occurs most often in the summer months from July through October. Its occurrence for Port Angeles is displayed in Table A-2. At Tatoosh Island heavy fog is present on more than half the days during August on average. In the Strait, at Port Angeles, heavy fog occurs on average 5-10 days a month from July to October, while only occurring 1-3 days a month the rest of the year.

5. Currents, Tides, Waves and Hydrographic Profiles

The Strait of Juan de Fuca is an extensive inland waterway that connects Puget Sound and the Strait of Georgia with the Pacific Ocean. It is part of the greater inland estuarine water system (OIW, 1980). The physical characteristics of the waters of the Strait have seasonal variability and depend upon tidal range, fresh water outflow, wind speed, wave energy, distance from the open ocean and complexity of the channel geometry. The Strait is long, narrow and deep. It is 165 km long, varying from 22 km wide at Cape Flattery to 28 km wide at Race Rocks-Port Angeles, where it then narrows to 18 km. The water depth is greatest at the western end, reaching 275 meters.

A) Currents

Due to the somewhat uniform channel and the distance from direct freshwater input, the surface tidal currents in the western Strait are relatively straightforward. The surface waters of the region near the mouth are strongly influenced by ocean currents and coastal winds. The maximum tidal surface currents lag behind the maximum high or low tide by 1-1.5 hours at the mouth. In the area between Race Rocks and Port Angeles there is only a short lag time between maximum range of the tide and maximum tidal surface currents. During a flood tide the surface currents along the outer Washington coast are directed into the Strait. Initially the currents are directed northeast across the channel toward Vancouver island, but further inland the confining nature of the channel directs the currents parallel to the channel. During large flood tides, the surface currents are flowing at speeds of 75-130 m/s down the channel.

Wind-generated currents in the western Strait of Juan de Fuca can become quite pronounced because of the funneling effect of the surrounding mountains. In general eastward blowing winds will deflect surface currents toward the southern shore, whereas westward blowing winds will deflect surface currents toward the north shore.

The coastal currents at the entrance of the Strait are similar to those described for the mouth of the Columbia River. There is a net landward movement of bottom water mainly on the south side of the Strait. Once inside the Strait there is some cross channel movement, then outward flow back to sea on the north side. Some of the water entering the Strait moves onshore and to the surface within 80 km of the mouth on both the south and north side. The submarine canyon at the mouth of the Strait acts as a partial barrier to northward flow of bottom currents along the open coast and deflects a large fraction into the mouth of the Strait (Barnes *et al.*, 1972).

The Strait of Juan de Fuca has a basic two-layer estuarine flow system typical of inland water bodies connected to the open ocean which receive significant amounts of river inflow (OIW, 1980). Inflowing river water mixes with marine waters in the estuary, forming a low-salinity surface layer that flows seaward. Denser seawater flows into the estuary below 100 meters replacing the saltwater that is mixed into the surface freshwater layer that flows out of the estuary. The Strait allows for outflow of the low-salinity surface waters from the estuary into the open ocean and for the inflow of more saline marine waters into the estuary. The volume of marine water flowing into the Strait is estimated to be 18 times the average freshwater outflow of the Columbia River. (Barnes *et al.*, 1972). The inflow into the Strait at depth has been computed by Barnes *et al.* (1972) to average 13×10^4 m^3 sec^{-1}. The minimum calculated flow is 6×10^4 m^3 sec^{-1} in the winter. The maximum calculated flow in the summer is 26×10^4 m^3 sec^{-1}. The net speed of these calculated currents is 2.6 km/day (Barnes *et al*, 1972).

The estuarine currents of the Strait have a net surface outflow in the top 100 meters due to freshwater input from the major rivers feeding into the inland portions of the estuary. The average net seaward surface flow attributed to estuarine currents averages 10-20 cm/s. During maximum freshwater outflow of early summer the estuarine component of surface flow can reach 40 cm/s at mid-channel in the mouth of the western Strait. The estuarine component of net bottom water inflow into he Strait is estimated to by 10 cm/s. Strong seaward flows occur during the summer when river flow, particularly from the Fraser River, is high, and the northwesterly prevailing winds drive nearshore waters of the Pacific away from the coast. This increases the east-west hydraulic head of the Strait, assuring the outflow of the surface waters (Thomson, 1981). Due to the Coriolis effect and curvature of the channel, the maximum inflow into the Strait is along the south side of the channel bottom and maximum outflow is along the north side of the surface waters.

Though there is a net outflow of the surface waters, there are occasional periods when the direction of surface water movement stalls or has short term reversal of a few days. These reversals occur during periods of low river outflow and when prevailing winds are from the south. These conditions typically occur during fall and winter and are associated with southwesterly storms. The south winds drive coastal ocean waters eastward, toward shore and into the mouth of the Strait. This current opposes the seaward flow of the surface waters and causes a sea level rise at the mouth of the Strait (Thomson, 1981). These reversed, landward flowing surface currents occur from 3-10 days per winter and average a speed of 50 cm/s. They persist for a day or two. The current reversal will extend landward as far as Race Rocks. During these reversals, flood currents are strengthened and ebb currents weakened.

B) Tides

The tides of the western Strait of Juan de Fuca are mixed, though predominantly semidiurnal. That is, two high tides and two low tides of unequal heights occur daily. The tidal range decreases eastward through the Strait to Victoria Harbour and then increases to the east and north. The tidal range is approximately 2.4 meters at the mouth off Cape Flattery, and near 2.0 meters at Port Angeles (Thomson, 1981).

The Coriolis effect has a clear influence on the tidal range. The rightward deflection causes higher tides to occur slightly earlier on the Washington side as the incoming flood waters are deflected to the right side of the Strait. It takes 1.5 to 3.5 hours for all of the stages of high tide to propagate from the entrance to the San Juan Islands. A progressive change occurs in the nature of the tide as it propagates to the east in the Strait; there is a distinct predominance of a diurnal inequity in the heights and times of successive high tides. The effects of the moon's declination predominate over the semidiurnal constituents of the tide farther to the west. Diurnal tides have only one high and one low during each tidal day. The inequity reaches its greatest expression in Victoria Harbour where the tides are nearly completely diurnal. The point where the diurnal constituent begins to dominate is in the region near Port Angeles, thus further discussion of its effects will be presented in the following section on the Eastern Strait of Juan de Fuca.

C) Waves

Maximum wave heights have been calculated (Harris, 1954) for storm events during the different strong wind seasons. During the winter, maximum wave heights in the western Strait were calculated to reach 13 feet with a strong westerly wind, while with a strong northeasterly wind the maximum wave heights were calculated for the region between the San Juan Islands and the Olympic Peninsula. These waves were calculated to reach 15 feet. During the summer when strong winds can occur two out of three days in the western Strait, wave heights of 7 feet can be expected.

D) Hydrographic Profiles

The water salinity measured during 1953 and 1954 in mid-channel near Low Point averages a low of 29-30 ppt in the summer months. This is during periods of high discharge from the Fraser and Skagit Rivers. The highest recorded salinity averaged 30-32 ppt in the late winter when river discharge is low. At depths below 100 meters, salinity is generally lowest during the winter when the water column is not well stratified and surface waters mix with deeper water. The maximum occurs during the summer when thermal stratification is greatest and more saline, upwelled deep marine water inflows into the Strait (OIW, 1980).

6. Shoreline Morphology, Characteristics and Environmental Conditions

The Washington coast of the western Strait of Juan de Fuca consists of alternating rocky headlands, wave-cut terraces, and gravel and sand beaches to the west of Freshwater Bay, and of gravel and sand beaches backed by eroding cliffs of glacial sediments to the east. Large man-made structures are found at Neah Bay, Ediz Hook, and Port Angeles harbor. Coastal features and processes governing their geomorphology are discussed in the following section. Information similar to that already presented for the outer coast of Washington is not repeated in detail.

A) Rocky Shorelines

Exposed steep cliffs and headlands are found at Cape Flattery, between Crescent Bay and Freshwater Bay, and at other scattered locations in the western sector of the Strait's coastline. Characteristics are generally similar to those of the cliffs and headlands along the northern Washington outer coast, although wave-energy and erosion rates are not as extreme within the semi-protected waters of the Strait. Drift is limited along the headlands and cliffs and may vary with season: east in summer, west in winter.

Wave-cut platforms, often rocky and irregular, are found at Cape Flattery, from near Sekiu to Pillar Point, and from Twin to Agate Bay. Narrow, coarse-grained beaches of cobble gravel or gravel often accumulate near the backing headlands of wave-cut platforms along the western Strait. Drift is generally eastward. However, weak western drift is shown along the platform from Clallam Bay to Pillar Point.

Sheltered rocky shores and headlands are not a significant feature along the coast of this region.

B) Sediment Shorelines

Mixed sand and gravel make up most of the beach features along the shores of the western Strait region.

Pocket or bayhead beaches, such as Clallam Bay and Crescent Bay, can be found in the western sector of this region. Sediment for this type of beach is supplied from the surrounding highlands; drift input from distant shores is minimal. Drift cells are usually limited by the headlands defining the pocket beach, so beach sediments tend to be stable, although seasonal shifts and changes due to construction of man-made structures are common. Pocket beach sediments of this region are generally mixed sand and gravel, although a few beaches are composed of cobbles and sand.

Spits and bars form along this coastal region, the best example being Ediz Hook which protects the harbor at Port Angeles. This is a narrow ridge built of accreted sand and gravel carried east from eroding cliffs and the Elwha River. Drift is strongly eastward outside of this spit and weakly westward in the protected harbor within. Construction west of Port Angeles and a dam on the Elwha have so reduced sediment input that Ediz Hook requires extensive foreshore revetment and periodic beach nourishment by the U.S. Army Corps of Engineers to combat erosion (Downing, 1983). Other spits and bars, such as those at the mouth of the Elwha or east of Sekiu, are very small and do not differ significantly from beaches nearby.

Tombolos are not found along this stretch of coastline, as offshore islands and rocks are very rare. Cuspate forelands are not present on the Washington shores of the western Strait of Juan de Fuca and barrier beaches are generally found only on open ocean coastlines.

Deltas are not common along the Strait of Juan de Fuca coastline. Angeles Point is a small delta formed at the mouth of the Elwha River, which drains the center of the Olympic Mountains. Sediment has been deposited here faster than drift has removed it and this type of sediment accumulation has resulted in the building of Ediz Hook and Dungeness Spit. Extensive erosion began at Ediz Hook with damming of the Elwha River; the effects at Angeles Point are so far less clear. Beach sediments, mixed sand and gravel, form a small spit/bar complex at the river mouth.

Tide flats and salt marshes are not extensive in this region. Small tide flats are found near Neah Bay and Pillar Point; salt marshes exist at the Neah Bay Radio Ranging Station, Pillar Point, and Salt Creek in Crescent Bay. A large tide flat-salt marsh system was filled during construction of Port Angeles Harbor. Shore-drift is usually onshore, in toward tide flat and salt marsh features along the Strait's coastline.

C) Man-made Structures

Man-made structures can be found at several locations along the Washington coast of the western Strait of Juan de Fuca Strait. A large breakwater is built at Neah Bay between the Cape Flattery Peninsula and Waadah Island, with harbor and marina development in the sheltered waters behind the breakwater. Riprap reinforces short segments of the coast on either side of the town of Sekiu; a few piers and a small marina are also located here. Riprap and other reinforcement is present at the marshy mouth of the Pyscht River and near the boat launch at Twin. Riprap protects nearly all the west side of Ediz Hook, some of its eastern side, and also parts of the interior of Port Angeles Harbor. Piers, marinas, retaining walls, and other harbor features are found on all sides of this bay.

7. Bottom Sediments

Bottom sediment distribution in the Strait of Juan de Fuca is shown in Figure A-1. The sediments tend to be coarse due to Pleistocene glacial activity. Gravel and sand banks, perhaps representing recessional moraines or outwash channels, are present. Seafloor mapping is made difficult by the local complexity common to glacial deposits. A combination of sand, gravel, and mud (probably glacial outwash covered with a thin coat of post-glacial river silt) makes up most of the bottom deposits, although near the Washington shore coarser sediments are found (sand and gravel or mud and gravel). Irregular regions of sand and gravel found in the eastern part of the Strait are probably related to temporary ice sheet stabilization over the San Juan Islands during recession (Chrzastowski, M.J., 1980). Glacial outwash from the Elwha River forms much of the coarse nearshore deposits near Port Angeles and Dungeness Spit. Transport mechanics for the Strait of Juan de Fuca sediments have not been investigated in detail for this report.

EASTERN STRAIT OF JUAN DE FUCA

1. Geological Setting

The eastern Strait of Juan de Fuca is the eroded and deepened floodplain and channel of an earlier Fraser River. The large fiord-like inlets and sounds typical of the Pacific Northwest were created through the scouring action of at least three great Pleistocene ice sheets covering western Canada and northern Washington. Local bedrock highs were polished by the ice and eroded somewhat, now to be exposed as isolated highlands or island groups such as the San Juan Islands.

2. Geological Characteristics

Along the eastern Strait of Juan de Fuca from Port Angeles to Port Townsend high cliffs of semi-consolidated glacial and non-glacial sediments are found, typically fronted by mixed sand and gravel beaches developed on wave-eroded terraces cut into the cliff-forming deposits. Erosion of the cliffs supplies most of the beach sediment. Similar beaches are present at other locations having no cliffs and maintained through littoral drift.

Dungeness Spit is a very large sand and gravel spit complex including extensive tide flats located between Port Angeles and Port Townsend; smaller spits and tide flats can be found near Sequim Bay and Port Discovery. Net drift along the eastern Strait is generally toward Dungeness Spit, although along the Quimper Peninsula drift is to the east, as is common for the western Strait. At the Point Roberts peninsula shore drift is northward. Near and within re-entrants, such as Port Discovery, drift patterns are complex, involving numerous reversals and small drift cells; drift rates at these protected sites are typically low. Small sections of beach have been modified at Point Roberts, otherwise development is rare along the coast of this region.

3. Bathymetry

East of the sill, at the east end of the Juan de Fuca Strait, channels cut through several shallow banks. The deepest channels lead into Haro Strait, while smaller channels enter Rosario Strait, Admiralty Inlet, and Deception Passage. Haro Strait and Rosario Strait are the primary junctions between the Juan de Fuca Strait and the Strait of Georgia.

4. Meteorology

Climate and meteorology of the eastern Strait are essentially similar to the western Strait. Refer to that section for details.

5. Currents, Tides, Waves and Hydrographic Profiles

The main features affecting the tidal components found in the Strait of Juan de Fuca have been discussed in detail for the western Straits of Juan de Fuca. As previously described the Strait is long, narrow, and deep. After narrowing to a width of 18 km at Race Rocks-Port Angeles, it widens to 56 km at the eastern boundary near Whidbey Island. The salinities are comparable to those identified in the Western Straits of Juan de Fuca, with the exception that the eastern region tends to be affected by brackish water flows; this leaves the eastern portion of the straits less saline than the western. In general the eastern area has measured seasonal salinities ranging from 28 to 31 ppt.

Prevailing wind patterns for the Strait of Juan de Fuca have been described previously. However, winds in the eastern portion of the Strait tend to be complex given the divergence in airflow. In the winter, winds blow predominantly from the west and southwest; in the summer, the winds are mainly from the northwest. In general, the eastern portion of the Straits receive less intense exposure to high winds in comparison with the western Straits. Offshore winds along the Strait have been used to estimate wave impacts as limited wave measurement for the Straits exist. In the eastern region, with lower measured wind speeds, the predicted wave heights could be slightly lower than those predicted in the western portion.

At the mouth of the Strait, the tide is mixed, mainly semidiurnal; however, east of Port Angeles, the tide becomes mixed, mainly diurnal. This is due to the effect of the ocean tide travelling eastward and its speed and range changing with the changes in channel geometry. From Race Rocks to the southern Strait of Georgia the tides become diurnal. Near Victoria, the tide has only one pronounced high and low each day for about 20 days a month. This is due to the effect of the moon's declination.

Tidal currents in the Straits have been discussed in previous sections. However, because of the variation within the Strait of the standing progressive-type wave, the tidal height and tidal streams vary with distance along the Strait. As with most channels along the coast, the strength and duration of tidal streams are distorted by estuarine flow processes. Consequently, ebb currents tend to be stronger and longer in duration than flood in the top 100 meters and flood currents are stronger below 100 m depths.

Direct measurement of currents in the Strait of Juan de Fuca reveal that flow tends to be parallel to the channel at all tide stages. However, some variation does occur in the eastern section between Slip Point and Pillar Point. On the flood tide the current is predominantly west-east and clockwise eddies form at Pillar Point. No eddies are observed on the ebb tide. On the ebb tide, currents in excess of 50 cm/sec have been observed.

6. Shoreline Morphology, Characteristics and Environmental Conditions

The Washington coast of the eastern Strait of Juan de Fuca is characterized by mixed sand and gravel beaches, often developed on wave-cut terraces beneath eroding cliffs of semi-consolidated sediments. Dungeness Spit is a large spit and tidal flat complex. Coastal features and geologic processes governing their form are discussed below.

A) Rocky Shorelines

Rocky cliffs, headlands and sheltered rocky shores are not found along this segment of coast.

Wave-cut terraces are a common feature along the Point Roberts Peninsula and the outer Juan de Fuca Strait coastline from Port Angeles to Dungeness Spit and from Sequim Bay to Port Townsend as well as on the shores of Protection Island, although the material of the terraces and backing cliffs are semi-consolidated Pleistocene glacial and non-glacial sediments. Due to rapid erosion, relatively wide beaches have developed. These deposits reflect local cliff sediments and are typically sand and gravel, although sandy or cobble gravel beaches can also be found.

B) Sediment Shorelines

<u>Pocket or bayhead</u> beaches are not common in this region, although within Port Discovery and Sequim Bay beaches of this type are present. See their discussion in the western Strait section. Note that wave energy and drift have much lower magnitudes within these protected inlets than along the open Strait coast.

<u>Spits and bars</u> are found at several locations, with sediments similar to and governed by similar processes as those of the western Strait. The most striking example is Dungeness Spit, the largest in the study area. Two smaller spits have developed in the sheltered waters behind the major arm along with wide areas of tide flats and marshes. Sediment from the Dungeness River as well as material eroding from the large post-glacial Elwha delta and Ediz Hook feed this complex; the long term effects of dams on the Elwha and the extensive foreshore revetment at Ediz Hook on this spit are unknown. Smaller spits have developed at both sides of the entrance to Sequim Bay, the western one enclosing a small tidal lagoon and marsh.

<u>Tombolos</u> are not found along the eastern Strait of Juan de Fuca shoreline.

<u>Cuspate forelands</u> are large triangular or cusp-shaped beach deposits along the shore, hundreds of meters to kilometers in length, formed by either converging waves in the lee of an offshore shoal, seasonal changes in alongshore drift, or recurved spits which connect with the shore at both ends, often enclosing a marshy lagoon (Downing, 1983). They are common in this coastal region and within Puget Sound, making up many of the named points. Point Wilson, just north of Port Townsend where Fort Worden is located, is a good example. Both seasonal and long-term beach changes in beach morphology may be expected at these sites, similar to those of spits. Sediments are typical of the surrounding beaches and cliffs, usually composed of mixed sand and gravel.

<u>Barrier beaches</u> do not form along this region.

<u>Delta development</u> is not very significant along this coastal segment as the major stream in this region, the Dungeness River, flows into tide flats around complex Dungeness Spit without building a traditional delta. Smaller streams flow into the southern ends of both Port Discovery and Sequim Bay, as well as areas of tide flats and marshes. These features are discussed below.

<u>Tide flats and salt marshes</u> have been discussed in detail in the Outer Coast section. Several tide flats and/or salt marshes are found along the eastern Strait coastline; these are within the protected water behind Dungeness Spit, along the coast east of the spit, behind the small spit just west of the entrance

to Sequim Bay, at the southern extremities of both Sequim Bay and Port Discovery, and along part of the cuspate beach northeast of Port Townsend. Remnants of tide flats are also present along the developed harbor of Port Townsend to the south of the town.

C) Man-made Structures

Man-made structures of this region are concentrated along the harbor of Port Townsend. Piers, retaining walls, riprap, a marina and other harbor features are found all along the southeast-facing shoreline. The beach and tide flats to the northeast of the town have not been developed.

7. Bottom Sediments

Within the eastern Strait of Juan de Fuca deposition patterns and sediments are generally as described for the western Strait. Mixed deposits are present over much of the seafloor, probably glacial outwash sand and gravel covered with a thin coat of modern river silt. Sand and some gravel is found offshore around Dungeness Spit, a relict of the Dungeness post-glacial delta and sediment transported from the similar Elwha delta to the west. Mud and silt are found on the bottom of Sequim Bay and Port Discovery. Finer sediments from post-glacial and modern rivers tend to collect in the deeper as well as the calmer areas of the Strait and Sound, mixing with the coarser glacial deposits. On shallows and banks, such as the entrance sills to major arms of the Sound, currents sweep away silt and fine sediments leaving exposed glacial drift, usually sand and gravel outwash (Cullen *et al.*, 1977).

APPENDIX C
ANALYSIS OF SEASONAL RESOURCE SITUATION TABLES (ARS)

APPENDIX C

TABLE 1 SPRING RESOURCE SCORES FOR THE OUTER STRAITS OF JUAN DE FUCA
(Compensation Schedule Region # 2 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Outer Straits	**201**	**1884**	**5**	**5**	**5**	**15**	**3**	**4**	
ADJACENT SUBREGIONS POTENTIALLY BENEFITED BY DISPERSANT USE IN SUBREGION 201									
Cape Flattery	203	5.4	5	5	5	15	4	4	K
Neah Bay	204	4.3	5	5	5	15	2	4	TF,K
Neah Bay to Clallam Bay	205	12.9	5	5	5	15	2	3	K
Clallam Bay	206	3.2	5	5	5	15	2	3	K,SM
Clallam Bay to Cresent Bay	207	20.8	5	5	5	15	2	3	K
Cresent Bay	208	1.1	5	5	5	15	2	3	K,SM
Cresent Bay to Ediz Hook	209	9	5	5	5	15	2	3	K,E

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

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TABLE 2 SUMMER RESOURCE SCORES FOR THE OUTER STRAITS OF JUAN DE FUCA

(Compensation Schedule Region # 2 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Outer Straits	201	1884	3	5	5	13	2	4	
ADJACENT SUBREGIONS POTENTIALLY BENEFITED BY DISPERSANT USE IN SUBREGION 201									
Cape Flattery	203	5.4	3	4	5	12	3	4	K
Neah Bay	204	4.3	3	4	5	12	2	4	TF,K
Neah Bay to Clallam Bay	205	12.9	3	4	5	12	3	3	K
Clallam Bay	206	3.2	3	4	5	12	2	3	K,SM
Clallam Bay to Cresent Bay	207	20.8	3	4	5	12	3	3	K
Cresent Bay	208	1.1	3	4	5	12	2	3	K,SM
Cresent Bay to Ediz Hook	209	9	3	4	5	12	2	3	K,E

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

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TABLE 3 FALL RESOURCE SCORES FOR THE OUTER STRAITS OF JUAN DE FUCA
(Compensation Schedule Region # 2 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Outer Straits	**201**	**1884**	**3**	**4**	**5**	**12**	**5**	**3**	
ADJACENT SUBREGIONS POTENTIALLY BENEFITED BY DISPERSANT USE IN SUBREGION 201									
Cape Flattery	203	5.4	3	2.5	5	10.5	4	3	K
Neah Bay	204	4.3	3	2.5	5	10.5	2	3	TF,K
Neah Bay to Clallam Bay	205	12.9	3	2.5	5	10.5	3	2	K
Clallam Bay	206	3.2	3	2.5	5	10.5	2	2	K,SM
Clallam Bay to Cresent Bay	207	20.8	3	2.5	5	10.5	3	2	K
Cresent Bay	208	1.1	3	2.5	5	10.5	2	2	K,SM
Cresent Bay to Ediz Hook	209	9	3	2.5	5	10.5	2	2	K,E

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

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TABLE 4 WINTER RESOURCE SCORES FOR THE OUTER STRAITS OF JUAN DE FUCA
(Compensation Schedule Region # 2 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Outer Straits	**201**	**1884**	**4**	**4**	**5**	**13**	**4**	**2**	
ADJACENT SUBREGIONS POTENTIALLY BENEFITED BY DISPERSANT USE IN SUBREGION 201									
Cape Flattery	203	5.4	4	3	5	12	3	2	K
Neah Bay	204	4.3	4	3	5	12	2	2	TF,K
Neah Bay to Clallam Bay	205	12.9	4	3	5	12	2	2	K
Clallam Bay	206	3.2	4	3	5	12	2	2	K,SM
Clallam Bay to Cresent Bay	207	20.8	4	3	5	12	2	2	K
Cresent Bay	208	1.1	4	3	5	12	2	2	K,SM
Cresent Bay to Ediz Hook	209	9	4	3	5	12	4	2	K,E

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

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TABLE 5 SPRING RESOURCE SCORES FOR THE INNER STRAITS OF JUAN DE FUCA

(Compensation Schedule Region # 3 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Inner Straits	301	1631	5	5	5	15	3	4	
ADJACENT SUBREGIONS POTENTIALLY BENEFITED BY DISPERSANT USE IN SUBREGION 301									
Ediz Hook	302	0.4	5	5	5	15	1	4	K
Port Angeles	303	10.4	5	5	5	15	2	4	
Voice of America	304	24	5	5	5	15	2	4	K
Dungeness Spit	305	4	5	5	5	15	2	4	K
Dungeness Spit/Harbor	306	12	5	5	5	15	4	4	TF
Jamestown	307	21.4	5	5	5	15	5	4	TF ,K,E
Sequim Bay	308	13.8	5	5	5	15	2	4	SM ,K
Miller Peninsula	309	4.8	5	5	5	15	2	4	K
Protection Island	310	3.1	5	5	5	15	4	4	K
Discovery Bay	311	37.1	5	5	5	15	3	4	TF,K
Quimper Peninsula	312	10.7	5	5	5	15	2	4	K
Whidbey Island	313	21	5	5	5	15	1	4	K
Smith Island	314	0.3	5	5	5	15	3	4	
Deception Pass	315	5.6	5	5	5	15	2	4	
Lopez Island (South Shore)	316	8.9	5	5	5	15	5	4	
San Juan Is, (South Shore)	317	3.5	5	5	5	15	2	4	K

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

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TABLE 6 SUMMER RESOURCE SCORES FOR THE INNER STRAITS OF JUAN DE FUCA

(Compensation Schedule Region # 3 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Inner Straits	**301**	**1631**	**3**	**5**	**5**	**13**	**3**	**4**	
ADJACENT SUBREGIONS POTENTIALLY BENEFITED BY DISPERSANT USE IN SUBREGION 301									
Ediz Hook	302	0.4	3	4	5	12	1	4	K
Port Angeles	303	10.4	3	4	5	12	3	4	
Voice of America	304	24	3	4	5	12	2	4	K
Dungeness Spit	305	4	3	4	5	12	2	4	K
Dungeness Spit/Harbor	306	12	3	4	5	12	2	4	TF
Jamestown	307	21.4	3	4	5	12	5	4	TF ,K,E
Sequim Bay	308	13.8	3	4	5	12	1	4	SM ,K
Miller Peninsula	309	4.8	3	4	5	12	2	4	K
Protection Island	310	3.1	3	4	5	12	5	4	K
Discovery Bay	311	37.1	3	4	5	12	1	4	TF,K
Quimper Peninsula	312	10.7	3	4	5	12	3	4	K
Whidbey Island	313	21	3	4	5	12	2	4	K
Smith Island	314	0.3	3	4	5	12	5	4	
Deception Pass	315	5.6	3	4	5	12	2	4	
Lopez Island (South Shore)	316	8.9	3	4	5	12	4	4	
San Juan Is, (South Shore)	317	3.5	3	4	5	12	2	4	K

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

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TABLE 7 FALL RESOURCE SCORES FOR THE INNER STRAITS OF JUAN DE FUCA
(Compensation Schedule Region # 3 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Inner Straits	**301**	**1631**	**3**	**4**	**5**	**12**	**3**	**4**	
ADJACENT SUBREGIONS POTENTIALLY BENEFITED BY DISPERSANT USE IN SUBREGION 301									
Ediz Hook	302	0.4	3	3	5	11	1	4	K
Port Angeles	303	10.4	3	3	5	11	3	4	
Voice of America	304	24	3	3	5	11	2	4	K
Dungeness Spit	305	4	3	3	5	11	2	4	K
Dungeness Spit/Harbor	306	12	3	3	5	11	2	4	TF
Jamestown	307	21.4	3	3	5	11	5	4	TF ,K,E
Sequim Bay	308	13.8	3	3	5	11	1	4	SM ,K
Miller Peninsula	309	4.8	3	3	5	11	2	4	K
Protection Island	310	3.1	3	3	5	11	5	4	K
Discovery Bay	311	37.1	3	3	5	11	1	4	TF,K
Quimper Peninsula	312	10.7	3	3	5	11	3	4	K
Whidbey Island	313	21	3	3	5	11	2	4	K
Smith Island	314	0.3	3	3	5	11	5	4	
Deception Pass	315	5.6	3	3	5	11	2	4	
Lopez Island (South Shore)	316	8.9	3	3	5	11	4	4	
San Juan Is, (South Shore)	317	3.5	3	3	5	11	2	4	K

K - KELP   E - EEL GRASS   TF - TIDE FLAT   SM - SALT MARSH

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TABLE 8 WINTER RESOURCE SCORES FOR THE INNER STRAITS OF JUAN DE FUCA

(Compensation Schedule Region # 3 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Inner Straits	**301**	**1631**	**4**	**4**	**5**	**13**	**4**	**3**	
ADJACENT SUBREGIONS POTENTIALLY BENEFITED BY DISPERSANT USE IN SUBREGION 301									
Ediz Hook	302	0.4	4	3	5	12	1	3	K
Port Angeles	303	10.4	4	3	5	12	2	3	
Voice of America	304	24	4	3	5	12	2	3	K
Dungeness Spit	305	4	4	3	5	12	3	3	K
Dungeness Spit/Harbor	306	12	4	3	5	12	3	3	TF
Jamestown	307	21.4	4	3	5	12	5	3	TF ,K,E
Sequim Bay	308	13.8	4	3	5	12	2	3	SM ,K
Miller Peninsula	309	4.8	4	3	5	12	3	3	K
Protection Island	310	3.1	4	3	5	12	3	3	K
Discovery Bay	311	37.1	4	3	5	12	4	3	TF,K
Quimper Peninsula	312	10.7	4	3	5	12	4	3	K
Whidbey Island	313	21	4	3	5	12	2	3	K
Smith Island	314	0.3	4	3	5	12	3	3	
Deception Pass	315	5.6	4	3	5	12	2	3	
Lopez Island (South Shore)	316	8.9	4	3	5	12	3	3	
San Juan Is, (South Shore)	317	3.5	4	3	5	12	2	3	K

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

APPENDIX C

TABLE 9 SPRING RESOURCE SCORES FOR THE OUTER COAST

(Compensation Schedule Region # 1 - WAC 173-183)

			COMPENSATION TABLE RANKING SCORES - WAC 173-183-400						
	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Inner Shelf	**109**		**5**	**5**	**5**	**15**	**4**	**5**	
Outer Shelf	**110**		**4**	**5**	**1**	**10**	**4**	**4**	
Shelf Edge	**111**		**4**	**2**	**1**	**7**	**5**	**4**	
Continental Slope	**112**		**2**	**2**	**1**	**5**	**2**	**1**	
ADJACENT SUBREGIONS POTENTIALLY BENEFITED BY DISPERSANT USE IN SUBREGIONS 110-112									
Northern Outer Coast	101		5	5	4	**14**	5	5	K,TF,SM
Kalaloch	102		5	5	5	**15**	5	5	
Quinault	103		5	5	3	**13**	5	5	
Copalis Beach	104		5	5	4	**14**	5	5	SM
Grays Harbor	105		5	5	2	**12**	5	5	TF, SM,E
Twin Harbors Beach	106		5	5	3	**13**	5	5	
Willapa Bay	107		5	5	4	**14**	5	5	TF, SM,E
Long Beach	108		5	5	4	**14**	5	5	

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

APPENDIX C

TABLE 10 SUMMER RESOURCE SCORES FOR THE OUTER COAST

(Compensation Schedule Region # 1 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Inner Shelf	**109**		**3**	**5**	**5**	**13**	**2**	**5**	
Outer Shelf	**110**		**2**	**5**	**1**	**8**	**1**	**3**	
Shelf Edge	**111**		**1**	**2**	**1**	**4**	**1**	**3**	
Continental Slope	**112**		**1**	**2**	**1**	**4**	**1**	**1**	
ADJACENT SUBREGIONS POTENTIALLY BENEFITED BY DISPERSANT USE IN SUBREGIONS 110-112									
Northern Outer Coast	101		3	4	4	11	5	5	K,TF,SM
Kalaloch	102		3	4	5	12	5	5	
Quinault	103		3	4	3	10	5	5	
Copalis Beach	104		3	4	4	11	5	5	SM
Grays Harbor	105		5	4	2	11	5	4	TF, SM,E
Twin Harbors Beach	106		3	4	3	10	5	5	
Willapa Bay	107		5	4	4	13	5	5	TF, SM,E
Long Beach	108		3	4	3	10	5	5	

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

APPENDIX C

TABLE 11 FALL RESOURCE SCORES FOR THE OUTER COAST

(Compensation Schedule Region # 1 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Inner Shelf	**109**		**3**	**4**	**5**	**12**	**5**	**5**	
Outer Shelf	**110**		**2**	**4**	**1**	**7**	**1**	**3**	
Shelf Edge	**111**		**2**	**2**	**1**	**5**	**1**	**3**	
Continental Slope	**112**		**1**	**2**	**1**	**4**	**1**	**1**	
ADJACENT SUBREGIONS POTENTIALLY BENEFITED BY DISPERSANT USE IN SUBREGIONS 110-112									
Northern Outer Coast	101		3	3	4	**10**	5	5	K,TF,SM
Kalaloch	102		3	3	5	**11**	5	5	
Quinault	103		3	3	3	**9**	5	5	
Copalis Beach	104		3	3	4	**10**	5	5	SM
Grays Harbor	105		5	3	2	**10**	5	5	TF, SM,E
Twin Harbors Beach	106		3	3	2	**8**	5	5	
Willapa Bay	107		5	3	4	**12**	5	5	TF, SM,E
Long Beach	108		3	3	3	**9**	5	5	

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

APPENDIX C

TABLE 12 WINTER RESOURCE SCORES FOR THE OUTER COAST

(Compensation Schedule Region # 1 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Inner Shelf	**109**		**4**	**4**	**5**	**13**	**5**	**5**	
Outer Shelf	**110**		**4**	**4**	**1**	**9**	**1**	**3**	
Shelf Edge	**111**		**3**	**2**	**1**	**6**	**1**	**3**	
Continental Slope	**112**		**1**	**2**	**1**	**4**	**1**	**1**	
ADJACENT SUBREGIONS POTENTIALLY BENEFITED BY DISPERSANT USE IN SUBREGIONS 110-112									
Northern Outer Coast	101		5	3	4	**12**	5	5	K,TF,SM
Kalaloch	102		5	3	5	**13**	5	5	
Quinault	103		5	3	3	**11**	5	5	
Copalis Beach	104		5	3	4	**12**	5	4	SM
Grays Harbor	105		5	3	2	**10**	5	4	TF, SM,E
Twin Harbors Beach	106		4	3	2	**9**	5	4	
Willapa Bay	107		5	3	4	**12**	5	4	TF, SM,E
Long Beach	108		4	3	3	**10**	5	5	

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

APPENDIX C

TABLE 13 SPRING RESOURCE SCORES FOR THE STRAITS OF GEORGIA

(Compensation Schedule Regions # 6 & 7 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Eastern Georgia Strait	**608**	**288.3**	**5**	**5**	**5**	**15**	**4**	**4**	
Western Georgia Strait	**703**	**364.5**	**5**	**5**	**5**	**15**	**2**	**4**	
ADJACENT SUBREGIONS POTENTIALLY PROTECTED BY DISPERSANT USE IN SUBREGIONS 608 and 703									
Lummi Bay	601	25	5	5	5	15	5	4	SM.TF
Cherry Point	602	14.1	5	5	5	15	5	4	
Birch Bay	603	19	5	5	5	15	4	4	E,TF
Semiahoo Spit	604	9.5	5	5	5	15	4	4	
Drayton Harbor	605	12.8	5	5	5	15	3	4	E,TF,SM
San Juan Is. - Northern Tier	607	34.4	5	5	5	15	3	4	
Point Roberts	701	16.3	5	5	5	15	4	4	
Northern Rosario Strait	903	92.2	5	5	4	14	5	4	K
President Channel	1001	103.6	5	5	4	14	2	5	K
Northern Areas	1002	50	5	5	4	14	1	5	K

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

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TABLE 14 SUMMER RESOURCE SCORES FOR THE STRAITS OF GEORGIA

(Compensation Schedule Regions # 6 & 7 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Eastern Georgia Strait	**608**	**288.3**	**3**	**5**	**5**	**13**	**4**	**4**	
Western Georgia Strait	**703**	**364.5**	**3**	**5**	**5**	**13**	**2**	**4**	
ADJACENT SUBREGIONS POTENTIALLY PROTECTED BY DISPERSANT USE IN SUBREGIONS 608 and 703									
Lummi Bay	601	25	3	4	5	12	5	4	SM.TF
Cherry Point	602	14.1	3	4	5	12	5	4	
Birch Bay	603	19	3	4	5	12	4	4	E,TF
Semiahoo Spit	604	9.5	3	4	5	12	4	4	
Drayton Harbor	605	12.8	3	4	5	12	3	4	E,TF,SM
San Juan Is. - Northern Tier	607	34.4	3	4	5	12	3	4	
Point Roberts	701	16.3	3	4	5	12	4	4	
Northern Rosario Strait	903	92.2	3	4	3	10	5	4	K
President Channel	1001	103.6	3	4	3	10	2	4	K
Northern Areas	1002	50	3	4	3	10	1	4	K

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

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TABLE 15 FALL RESOURCE SCORES FOR THE STRAITS OF GEORGIA

(Compensation Schedule Regions # 6 & 7 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Eastern Georgia Strait	**608**	**288.3**	**3**	**4**	**4**	**11**	**4**	**4**	
Western Georgia Strait	**703**	**364.5**	**3**	**4**	**4**	**11**	**2**	**4**	
ADJACENT SUBREGIONS POTENTIALLY PROTECTED BY DISPERSANT USE IN SUBREGIONS 608 and 703									
Lummi Bay	601	25	3	3	4	**10**	3	4	SM.TF
Cherry Point	602	14.1	3	3	4	**10**	2	4	
Birch Bay	603	19	3	3	4	**10**	3	4	E,TF
Semiahoo Spit	604	9.5	3	3	4	**10**	4	4	
Drayton Harbor	605	12.8	3	3	4	**10**	3	4	E,TF,SM
San Juan Is. - Northern Tier	607	34.4	3	3	4	**10**	2	4	
Point Roberts	701	16.3	3	3	4	**10**	2	4	
Northern Rosario Strait	903	92.2	3	3	3	**9**	5	3	K
President Channel	1001	103.6	3	3	3	**9**	2	4	K
Northern Areas	1002	50	3	3	3	**9**	2	4	K

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

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TABLE 16 WINTER RESOURCE SCORES FOR THE STRAITS OF GEORGIA

(Compensation Schedule Regions # 6 & 7 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Eastern Georgia Strait	608	288.3	4	4	5	13	4	3	
Western Georgia Strait	703	364.5	4	4	5	13	2	3	
ADJACENT SUBREGIONS POTENTIALLY PROTECTED BY DISPERSANT USE IN SUBREGIONS 608 and 703									
Lummi Bay	601	25	4	3	5	12	4	3	SM.TF
Cherry Point	602	14.1	4	3	5	12	2	3	
Birch Bay	603	19	4	3	5	12	3	3	E,TF
Semiahoo Spit	604	9.5	4	3	5	12	4	3	
Drayton Harbor	605	12.8	4	3	5	12	4	3	E,TF,SM
San Juan Is. - Northern Tier	607	34.4	4	3	5	12	4	3	
Point Roberts	701	16.3	4	3	5	12	4	3	
Northern Rosario Strait	903	92.2	4	3	4	11	4	2	K
President Channel	1001	103.6	4	3	4	11	2	3	K
Northern Areas	1002	50	4	3	4	11	3	3	K

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

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TABLE 17 SPRING RESOURCE SCORES FOR THE HARO STRAITS

(Compensation Schedule Regions # 8 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Northern Haro Strait	801	338.7	5	5	4	14	2	5	K
Southern Haro Strait	802	224.4	5	5	4	14	1	5	K
ADJACENT SUBREGIONS POTENTIALLY PROTECTED BY DISPERSANT USE IN SUBREGIONS 801 and 802									
President Channel	1001	103.6	5	4	4	13	2	5	K
Speidan Channel	1101	13.7	5	4	4	13	1	3	K
Mosquito/Roche Complex	1201	6	5	4	4	13	2	3	K

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

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TABLE 18 SUMMER RESOURCE SCORES FOR THE HARO STRAITS

(Compensation Schedule Regions # 8 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Northern Haro Strait	801	338.7	3	5	3	11	2	4	K
Southern Haro Strait	802	224.4	3	5	3	11	1	4	K
ADJACENT SUBREGIONS POTENTIALLY PROTECTED BY DISPERSANT USE IN SUBREGIONS 801 and 802									
President Channel	1001	103.6	3	4	3	10	2	4	K
Speidan Channel	1101	13.7	3	4	3	10	1	3	K
Mosquito/Roche Complex	1201	6	3	4	3	10	2	3	K

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

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TABLE 19 FALL RESOURCE SCORES FOR THE HARO STRAITS

(Compensation Schedule Regions # 8 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Northern Haro Strait	801	338.7	3	4	3	10	4	4	K
Southern Haro Strait	802	224.4	3	4	3	10	1	4	K
ADJACENT SUBREGIONS POTENTIALLY PROTECTED BY DISPERSANT USE IN SUBREGIONS 801 and 802									
President Channel	1001	103.6	3	3	3	9	2	4	K
Speidan Channel	1101	13.7	3	3	3	9	2	3	K
Mosquito/Roche Complex	1201	6	3	3	3	9	2	3	K

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

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TABLE 20 WINTER RESOURCE SCORES FOR THE HARO STRAITS

(Compensation Schedule Regions # 8 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Northern Haro Strait	801	338.7	4	4	4	12	3	4	K
Southern Haro Strait	802	224.4	4	4	4	12	2	4	K
ADJACENT SUBREGIONS POTENTIALLY PROTECTED BY DISPERSANT USE IN SUBREGIONS 801 and 802									
President Channel	1001	103.6	4	2	4	10	2	3	K
Speidan Channel	1101	13.7	4	2	4	10	2	2	K
Mosquito/Roche Complex	1201	6	4	2	4	10	3	2	K

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

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ANALYSIS OF SEASONAL RESOURCE SITUATION TABLES (ARS)

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TABLE 1 SPRING RESOURCE SCORES FOR THE OUTER STRAITS OF JUAN DE FUCA
(Compensation Schedule Region # 2 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Outer Straits	**201**	**1884**	**5**	**5**	**5**	**15**	**3**	**4**	
ADJACENT SUBREGIONS POTENTIALLY BENEFITED BY DISPERSANT USE IN SUBREGION 201									
Cape Flattery	203	5.4	5	5	5	15	4	4	K
Neah Bay	204	4.3	5	5	5	15	2	4	TF,K
Neah Bay to Clallam Bay	205	12.9	5	5	5	15	2	3	K
Clallam Bay	206	3.2	5	5	5	15	2	3	K,SM
Clallam Bay to Cresent Bay	207	20.8	5	5	5	15	2	3	K
Cresent Bay	208	1.1	5	5	5	15	2	3	K,SM
Cresent Bay to Ediz Hook	209	9	5	5	5	15	2	3	K,E

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

APPENDIX C

TABLE 2 SUMMER RESOURCE SCORES FOR THE OUTER STRAITS OF JUAN DE FUCA
(Compensation Schedule Region # 2 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
**********	**********	**********	**********	**********	**********	***********	**********	**********	**********
POTENTIAL DISPERSANT USE SUBREGION									
Outer Straits	**201**	**1884**	**3**	**5**	**5**	**13**	**2**	**4**	
ADJACENT SUBREGIONS POTENTIALLY BENEFITED BY DISPERSANT USE IN SUBREGION 201									
Cape Flattery	203	5.4	3	4	5	12	3	4	K
Neah Bay	204	4.3	3	4	5	12	2	4	TF,K
Neah Bay to Clallam Bay	205	12.9	3	4	5	12	3	3	K
Clallam Bay	206	3.2	3	4	5	12	2	3	K,SM
Clallam Bay to Cresent Bay	207	20.8	3	4	5	12	3	3	K
Cresent Bay	208	1.1	3	4	5	12	2	3	K,SM
Cresent Bay to Ediz Hook	209	9	3	4	5	12	2	3	K,E
********** **********	**********	**********	**********	**********	**********	***********	**********	**********	**********

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

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TABLE 3 FALL RESOURCE SCORES FOR THE OUTER STRAITS OF JUAN DE FUCA
(Compensation Schedule Region # 2 - WAC 173-183)

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
			COMPENSATION TABLE RANKING SCORES - WAC 173-183-400						
POTENTIAL DISPERSANT USE SUBREGION									
Outer Straits	**201**	**1884**	**3**	**4**	**5**	**12**	**5**	**3**	
ADJACENT SUBREGIONS POTENTIALLY BENEFITED BY DISPERSANT USE IN SUBREGION 201									
Cape Flattery	203	5.4	3	2.5	5	10.5	4	3	K
Neah Bay	204	4.3	3	2.5	5	10.5	2	3	TF,K
Neah Bay to Clallam Bay	205	12.9	3	2.5	5	10.5	3	2	K
Clallam Bay	206	3.2	3	2.5	5	10.5	2	2	K,SM
Clallam Bay to Cresent Bay	207	20.8	3	2.5	5	10.5	3	2	K
Cresent Bay	208	1.1	3	2.5	5	10.5	2	2	K,SM
Cresent Bay to Ediz Hook	209	9	3	2.5	5	10.5	2	2	K,E

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

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TABLE 4 WINTER RESOURCE SCORES FOR THE OUTER STRAITS OF JUAN DE FUCA
(Compensation Schedule Region # 2 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Outer Straits	**201**	**1884**	**4**	**4**	**5**	**13**	**4**	**2**	
ADJACENT SUBREGIONS POTENTIALLY BENEFITED BY DISPERSANT USE IN SUBREGION 201									
Cape Flattery	203	5.4	4	3	5	12	3	2	K
Neah Bay	204	4.3	4	3	5	12	2	2	TF,K
Neah Bay to Clallam Bay	205	12.9	4	3	5	12	2	2	K
Clallam Bay	206	3.2	4	3	5	12	2	2	K,SM
Clallam Bay to Cresent Bay	207	20.8	4	3	5	12	2	2	K
Cresent Bay	208	1.1	4	3	5	12	2	2	K,SM
Cresent Bay to Ediz Hook	209	9	4	3	5	12	4	2	K,E

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

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TABLE 5 SPRING RESOURCE SCORES FOR THE INNER STRAITS OF JUAN DE FUCA

(Compensation Schedule Region # 3 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Inner Straits	**301**	**1631**	**5**	**5**	**5**	**15**	**3**	**4**	
ADJACENT SUBREGIONS POTENTIALLY BENEFITED BY DISPERSANT USE IN SUBREGION 301									
Ediz Hook	302	0.4	5	5	5	15	1	4	K
Port Angeles	303	10.4	5	5	5	15	2	4	
Voice of America	304	24	5	5	5	15	2	4	K
Dungeness Spit	305	4	5	5	5	15	2	4	K
Dungeness Spit/Harbor	306	12	5	5	5	15	4	4	TF
Jamestown	307	21.4	5	5	5	15	5	4	TF,K,E
Sequim Bay	308	13.8	5	5	5	15	2	4	SM,K
Miller Peninsula	309	4.8	5	5	5	15	2	4	K
Protection Island	310	3.1	5	5	5	15	4	4	K
Discovery Bay	311	37.1	5	5	5	15	3	4	TF,K
Quimper Peninsula	312	10.7	5	5	5	15	2	4	K
Whidbey Island	313	21	5	5	5	15	1	4	K
Smith Island	314	0.3	5	5	5	15	3	4	
Deception Pass	315	5.6	5	5	5	15	2	4	
Lopez Island (South Shore)	316	8.9	5	5	5	15	5	4	
San Juan Is, (South Shore)	317	3.5	5	5	5	15	2	4	K

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

APPENDIX C

TABLE 6 SUMMER RESOURCE SCORES FOR THE INNER STRAITS OF JUAN DE FUCA
(Compensation Schedule Region # 3 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Inner Straits	301	1631	3	5	5	13	3	4	
ADJACENT SUBREGIONS POTENTIALLY BENEFITED BY DISPERSANT USE IN SUBREGION 301									
Ediz Hook	302	0.4	3	4	5	12	1	4	K
Port Angeles	303	10.4	3	4	5	12	3	4	
Voice of America	304	24	3	4	5	12	2	4	K
Dungeness Spit	305	4	3	4	5	12	2	4	K
Dungeness Spit/Harbor	306	12	3	4	5	12	2	4	TF
Jamestown	307	21.4	3	4	5	12	5	4	TF ,K,E
Sequim Bay	308	13.8	3	4	5	12	1	4	SM ,K
Miller Peninsula	309	4.8	3	4	5	12	2	4	K
Protection Island	310	3.1	3	4	5	12	5	4	K
Discovery Bay	311	37.1	3	4	5	12	1	4	TF,K
Quimper Peninsula	312	10.7	3	4	5	12	3	4	K
Whidbey Island	313	21	3	4	5	12	2	4	K
Smith Island	314	0.3	3	4	5	12	5	4	
Deception Pass	315	5.6	3	4	5	12	2	4	
Lopez Island (South Shore)	316	8.9	3	4	5	12	4	4	
San Juan Is, (South Shore)	317	3.5	3	4	5	12	2	4	K

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

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TABLE 7 FALL RESOURCE SCORES FOR THE INNER STRAITS OF JUAN DE FUCA

(Compensation Schedule Region # 3 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Inner Straits	**301**	**1631**	**3**	**4**	**5**	**12**	**3**	**4**	
ADJACENT SUBREGIONS POTENTIALLY BENEFITED BY DISPERSANT USE IN SUBREGION 301									
Ediz Hook	302	0.4	3	3	5	11	1	4	K
Port Angeles	303	10.4	3	3	5	11	3	4	
Voice of America	304	24	3	3	5	11	2	4	K
Dungeness Spit	305	4	3	3	5	11	2	4	K
Dungeness Spit/Harbor	306	12	3	3	5	11	2	4	TF
Jamestown	307	21.4	3	3	5	11	5	4	TF ,K,E
Sequim Bay	308	13.8	3	3	5	11	1	4	SM ,K
Miller Peninsula	309	4.8	3	3	5	11	2	4	K
Protection Island	310	3.1	3	3	5	11	5	4	K
Discovery Bay	311	37.1	3	3	5	11	1	4	TF,K
Quimper Peninsula	312	10.7	3	3	5	11	3	4	K
Whidbey Island	313	21	3	3	5	11	2	4	K
Smith Island	314	0.3	3	3	5	11	5	4	
Deception Pass	315	5.6	3	3	5	11	2	4	
Lopez Island (South Shore)	316	8.9	3	3	5	11	4	4	
San Juan Is, (South Shore)	317	3.5	3	3	5	11	2	4	K

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

APPENDIX C

TABLE 8 WINTER RESOURCE SCORES FOR THE INNER STRAITS OF JUAN DE FUCA

(Compensation Schedule Region # 3 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Inner Straits	**301**	**1631**	**4**	**4**	**5**	**13**	**4**	**3**	
ADJACENT SUBREGIONS POTENTIALLY BENEFITED BY DISPERSANT USE IN SUBREGION 301									
Ediz Hook	302	0.4	4	3	5	12	1	3	K
Port Angeles	303	10.4	4	3	5	12	2	3	
Voice of America	304	24	4	3	5	12	2	3	K
Dungeness Spit	305	4	4	3	5	12	3	3	K
Dungeness Spit/Harbor	306	12	4	3	5	12	3	3	TF
Jamestown	307	21.4	4	3	5	12	5	3	TF ,K,E
Sequim Bay	308	13.8	4	3	5	12	2	3	SM ,K
Miller Peninsula	309	4.8	4	3	5	12	3	3	K
Protection Island	310	3.1	4	3	5	12	3	3	K
Discovery Bay	311	37.1	4	3	5	12	4	3	TF,K
Quimper Peninsula	312	10.7	4	3	5	12	4	3	K
Whidbey Island	313	21	4	3	5	12	2	3	K
Smith Island	314	0.3	4	3	5	12	3	3	
Deception Pass	315	5.6	4	3	5	12	2	3	
Lopez Island (South Shore)	316	8.9	4	3	5	12	3	3	
San Juan Is, (South Shore)	317	3.5	4	3	5	12	2	3	K

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

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TABLE 9 SPRING RESOURCE SCORES FOR THE OUTER COAST
(Compensation Schedule Region # 1 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Inner Shelf	**109**		**5**	**5**	**5**	**15**	**4**	**5**	
Outer Shelf	**110**		**4**	**5**	**1**	**10**	**4**	**4**	
Shelf Edge	**111**		**4**	**2**	**1**	**7**	**5**	**4**	
Continental Slope	**112**		**2**	**2**	**1**	**5**	**2**	**1**	
ADJACENT SUBREGIONS POTENTIALLY BENEFITED BY DISPERSANT USE IN SUBREGIONS 110-112									
Northern Outer Coast	101		5	5	4	**14**	5	5	K,TF,SM
Kalaloch	102		5	5	5	**15**	5	5	
Quinault	103		5	5	3	**13**	5	5	
Copalis Beach	104		5	5	4	**14**	5	5	SM
Grays Harbor	105		5	5	2	**12**	5	5	TF, SM,E
Twin Harbors Beach	106		5	5	3	**13**	5	5	
Willapa Bay	107		5	5	4	**14**	5	5	TF, SM,E
Long Beach	108		5	5	4	**14**	5	5	

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

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TABLE 10 SUMMER RESOURCE SCORES FOR THE OUTER COAST

(Compensation Schedule Region # 1 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Inner Shelf	**109**		**3**	**5**	**5**	**13**	**2**	**5**	
Outer Shelf	**110**		**2**	**5**	**1**	**8**	**1**	**3**	
Shelf Edge	**111**		**1**	**2**	**1**	**4**	**1**	**3**	
Continental Slope	**112**		**1**	**2**	**1**	**4**	**1**	**1**	
ADJACENT SUBREGIONS POTENTIALLY BENEFITED BY DISPERSANT USE IN SUBREGIONS 110-112									
Northern Outer Coast	101		3	4	4	11	5	5	K,TF,SM
Kalaloch	102		3	4	5	12	5	5	
Quinault	103		3	4	3	10	5	5	
Copalis Beach	104		3	4	4	11	5	5	SM
Grays Harbor	105		5	4	2	11	5	4	TF, SM,E
Twin Harbors Beach	106		3	4	3	10	5	5	
Willapa Bay	107		5	4	4	13	5	5	TF, SM,E
Long Beach	108		3	4	3	10	5	5	

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

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TABLE 11 FALL RESOURCE SCORES FOR THE OUTER COAST
(Compensation Schedule Region # 1 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Inner Shelf	**109**		**3**	**4**	**5**	**12**	**5**	**5**	
Outer Shelf	**110**		**2**	**4**	**1**	**7**	**1**	**3**	
Shelf Edge	**111**		**2**	**2**	**1**	**5**	**1**	**3**	
Continental Slope	**112**		**1**	**2**	**1**	**4**	**1**	**1**	
ADJACENT SUBREGIONS POTENTIALLY BENEFITED BY DISPERSANT USE IN SUBREGIONS 110-112									
Northern Outer Coast	101		3	3	4	**10**	5	5	K,TF,SM
Kalaloch	102		3	3	5	**11**	5	5	
Quinault	103		3	3	3	**9**	5	5	
Copalis Beach	104		3	3	4	**10**	5	5	SM
Grays Harbor	105		5	3	2	**10**	5	5	TF, SM,E
Twin Harbors Beach	106		3	3	2	**8**	5	5	
Willapa Bay	107		5	3	4	**12**	5	5	TF, SM,E
Long Beach	108		3	3	3	**9**	5	5	

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

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TABLE 12 WINTER RESOURCE SCORES FOR THE OUTER COAST

(Compensation Schedule Region # 1 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Inner Shelf	**109**		**4**	**4**	**5**	**13**	**5**	**5**	
Outer Shelf	**110**		**4**	**4**	**1**	**9**	**1**	**3**	
Shelf Edge	**111**		**3**	**2**	**1**	**6**	**1**	**3**	
Continental Slope	**112**		**1**	**2**	**1**	**4**	**1**	**1**	
ADJACENT SUBREGIONS POTENTIALLY BENEFITED BY DISPERSANT USE IN SUBREGIONS 110-112									
Northern Outer Coast	101		5	3	4	**12**	5	5	K,TF,SM
Kalaloch	102		5	3	5	**13**	5	5	
Quinault	103		5	3	3	**11**	5	5	
Copalis Beach	104		5	3	4	**12**	5	4	SM
Grays Harbor	105		5	3	2	**10**	5	4	TF, SM,E
Twin Harbors Beach	106		4	3	2	**9**	5	4	
Willapa Bay	107		5	3	4	**12**	5	4	TF, SM,E
Long Beach	108		4	3	3	**10**	5	5	

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

APPENDIX C

TABLE 13 SPRING RESOURCE SCORES FOR THE STRAITS OF GEORGIA

(Compensation Schedule Regions # 6 & 7 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Eastern Georgia Strait	**608**	**288.3**	**5**	**5**	**5**	**15**	**4**	**4**	
Western Georgia Strait	**703**	**364.5**	**5**	**5**	**5**	**15**	**2**	**4**	
ADJACENT SUBREGIONS POTENTIALLY PROTECTED BY DISPERSANT USE IN SUBREGIONS 608 and 703									
Lummi Bay	601	25	5	5	5	15	5	4	SM.TF
Cherry Point	602	14.1	5	5	5	15	5	4	
Birch Bay	603	19	5	5	5	15	4	4	E,TF
Semiahoo Spit	604	9.5	5	5	5	15	4	4	
Drayton Harbor	605	12.8	5	5	5	15	3	4	E,TF,SM
San Juan Is. - Northern Tier	607	34.4	5	5	5	15	3	4	
Point Roberts	701	16.3	5	5	5	15	4	4	
Northern Rosario Strait	903	92.2	5	5	4	14	5	4	K
President Channel	1001	103.6	5	5	4	14	2	5	K
Northern Areas	1002	50	5	5	4	14	1	5	K

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

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TABLE 14 SUMMER RESOURCE SCORES FOR THE STRAITS OF GEORGIA

(Compensation Schedule Regions # 6 & 7 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Eastern Georgia Strait	608	288.3	3	5	5	13	4	4	
Western Georgia Strait	703	364.5	3	5	5	13	2	4	
ADJACENT SUBREGIONS POTENTIALLY PROTECTED BY DISPERSANT USE IN SUBREGIONS 608 and 703									
Lummi Bay	601	25	3	4	5	12	5	4	SM.TF
Cherry Point	602	14.1	3	4	5	12	5	4	
Birch Bay	603	19	3	4	5	12	4	4	E,TF
Semiahoo Spit	604	9.5	3	4	5	12	4	4	
Drayton Harbor	605	12.8	3	4	5	12	3	4	E,TF,SM
San Juan Is. - Northern Tier	607	34.4	3	4	5	12	3	4	
Point Roberts	701	16.3	3	4	5	12	4	4	
Northern Rosario Strait	903	92.2	3	4	3	10	5	4	K
President Channel	1001	103.6	3	4	3	10	2	4	K
Northern Areas	1002	50	3	4	3	10	1	4	K

K - KELP   E - EEL GRASS   TF - TIDE FLAT   SM - SALT MARSH

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TABLE 15 FALL RESOURCE SCORES FOR THE STRAITS OF GEORGIA

(Compensation Schedule Regions # 6 & 7 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Eastern Georgia Strait	**608**	**288.3**	**3**	**4**	**4**	**11**	**4**	**4**	
Western Georgia Strait	**703**	**364.5**	**3**	**4**	**4**	**11**	**2**	**4**	
ADJACENT SUBREGIONS POTENTIALLY PROTECTED BY DISPERSANT USE IN SUBREGIONS 608 and 703									
Lummi Bay	601	25	3	3	4	**10**	3	4	SM.TF
Cherry Point	602	14.1	3	3	4	**10**	2	4	
Birch Bay	603	19	3	3	4	**10**	3	4	E,TF
Semiahoo Spit	604	9.5	3	3	4	**10**	4	4	
Drayton Harbor	605	12.8	3	3	4	**10**	3	4	E,TF,SM
San Juan Is. - Northern Tier	607	34.4	3	3	4	**10**	2	4	
Point Roberts	701	16.3	3	3	4	**10**	2	4	
Northern Rosario Strait	903	92.2	3	3	3	**9**	5	3	K
President Channel	1001	103.6	3	3	3	**9**	2	4	K
Northern Areas	1002	50	3	3	3	**9**	2	4	K

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

APPENDIX C

TABLE 16 WINTER RESOURCE SCORES FOR THE STRAITS OF GEORGIA

(Compensation Schedule Regions # 6 & 7 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Eastern Georgia Strait	608	288.3	4	4	5	13	4	3	
Western Georgia Strait	703	364.5	4	4	5	13	2	3	
ADJACENT SUBREGIONS POTENTIALLY PROTECTED BY DISPERSANT USE IN SUBREGIONS 608 and 703									
Lummi Bay	601	25	4	3	5	12	4	3	SM.TF
Cherry Point	602	14.1	4	3	5	12	2	3	
Birch Bay	603	19	4	3	5	12	3	3	E,TF
Semiahoo Spit	604	9.5	4	3	5	12	4	3	
Drayton Harbor	605	12.8	4	3	5	12	4	3	E,TF,SM
San Juan Is. - Northern Tier	607	34.4	4	3	5	12	4	3	
Point Roberts	701	16.3	4	3	5	12	4	3	
Northern Rosario Strait	903	92.2	4	3	4	11	4	2	K
President Channel	1001	103.6	4	3	4	11	2	3	K
Northern Areas	1002	50	4	3	4	11	3	3	K

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

APPENDIX C

TABLE 17 SPRING RESOURCE SCORES FOR THE HARO STRAITS

(Compensation Schedule Regions # 8 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Northern Haro Strait	**801**	**338.7**	**5**	**5**	**4**	**14**	**2**	**5**	**K**
Southern Haro Strait	**802**	**224.4**	**5**	**5**	**4**	**14**	**1**	**5**	**K**
ADJACENT SUBREGIONS POTENTIALLY PROTECTED BY DISPERSANT USE IN SUBREGIONS 801 and 802									
President Channel	1001	103.6	5	4	4	13	2	5	K
Speidan Channel	1101	13.7	5	4	4	13	1	3	K
Mosquito/Roche Complex	1201	6	5	4	4	13	2	3	K

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

APPENDIX C

TABLE 18 SUMMER RESOURCE SCORES FOR THE HARO STRAITS

(Compensation Schedule Regions # 8 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Northern Haro Strait	801	338.7	3	5	3	11	2	4	K
Southern Haro Strait	802	224.4	3	5	3	11	1	4	K
ADJACENT SUBREGIONS POTENTIALLY PROTECTED BY DISPERSANT USE IN SUBREGIONS 801 and 802									
President Channel	1001	103.6	3	4	3	10	2	4	K
Speidan Channel	1101	13.7	3	4	3	10	1	3	K
Mosquito/Roche Complex	1201	6	3	4	3	10	2	3	K

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

APPENDIX C

TABLE 19 FALL RESOURCE SCORES FOR THE HARO STRAITS

(Compensation Schedule Regions # 8 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Northern Haro Strait	**801**	**338.7**	**3**	**4**	**3**	**10**	**4**	**4**	**K**
Southern Haro Strait	**802**	**224.4**	**3**	**4**	**3**	**10**	**1**	**4**	**K**
ADJACENT SUBREGIONS POTENTIALLY PROTECTED BY DISPERSANT USE IN SUBREGIONS 801 and 802									
President Channel	1001	103.6	3	3	3	9	2	4	K
Speidan Channel	1101	13.7	3	3	3	9	2	3	K
Mosquito/Roche Complex	1201	6	3	3	3	9	2	3	K

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

APPENDIX C

TABLE 20 WINTER RESOURCE SCORES FOR THE HARO STRAITS

(Compensation Schedule Regions # 8 - WAC 173-183)

COMPENSATION TABLE RANKING SCORES - WAC 173-183-400

	COMP TABLE SUBREGION	SUBREGION SIZE (Sq. Km.)	MARINE FISH	SALMON	SHELLFISH	SUM OF FISH VALUES	BIRDS	MARINE MAMMALS	SENSITIVE HABITATS
POTENTIAL DISPERSANT USE SUBREGION									
Northern Haro Strait	801	338.7	4	4	4	12	3	4	K
Southern Haro Strait	802	224.4	4	4	4	12	2	4	K
ADJACENT SUBREGIONS POTENTIALLY PROTECTED BY DISPERSANT USE IN SUBREGIONS 801 and 802									
President Channel	1001	103.6	4	2	4	10	2	3	K
Speidan Channel	1101	13.7	4	2	4	10	2	2	K
Mosquito/Roche Complex	1201	6	4	2	4	10	3	2	K

K - KELP E - EEL GRASS TF - TIDE FLAT SM - SALT MARSH

APPENDIX D

FACTORS AFFECTING DISPERSANT EFFECTIVENESS

APPENDIX D
FACTORS AFFECTING DISPERSANT EFFECTIVENESS

Any response to marine oil pollution is usually difficult to organize and dependent upon many factors including the weather. The following discussion summarizes these major factors and their relationships to dispersant effectiveness.

Oil Characteristics

Oil Type: Chemical agents are not applicable for use on certain oils. The characteristics of nondispersible oils may be summarized as (1) non-spreading, which occurs when the pour point of the oil or product is higher than the ambient water temperature, (2) well-developed, water-in-oil emulsions (mousse), and (3) waxy or asphaltic crudes and highly viscous oils.

These characteristics are often predictable from a knowledge of what oil was spilled, the exposure time, and of the ambient seawater surface temperature. Even if this information is not available, it may be possible to carry out a small-scale field test to determine if the dispersant is effective.

Minas crude, Bass Strait, Lube, and heavy fuel oils are considered to be non-condusive to dispersants.

Time of Application: The majority of crude oils and products handled in the region are dispersible when fresh. However, under the weathering processes of evaporation and emulsification; (1) there are increases in the specific gravity and pour point of the increasingly heavy oil residue, (2) there is a tendency for water to be incorporated (mousse formation), and (3) both evaporation and emulsification increase the viscosity of the oil and increase the oil/water interfacial tension. Dispersant will also tend to "roll off" the oil patches into the water. Under these conditions, the effectiveness of chemical dispersants decreases rapidly. For this reason, the effectiveness of chemical dispersion is a function of the prompt treatment of the spilled oil. For example, tests have concluded that Prudhoe Bay crude oil is nondispersible after 3 days in summer. However, this window for dispersant effectiveness may be only about 8 hours in winter.

Other Oil Characteristics: Other characteristics of spilled oil may also contribute to the formation and stability of water-in-oil emulsions. For example, the effects of high pour point have already been noted. Chemical composition may account for the fact that oils with similar viscosity have shown differing responses to dispersants and vice versa. Pre-approval for field trials as soon as a spill occurs is consequently an important factor if the method is to be effective.

Locational and Climatic Conditions

1. Distance to Shoreline. The absolute distance to the shoreline is not as important to safe and effective chemical dispersion of an oil slick, as is the

dilution potential before the dispersed oil reaches sensitive resources (ITOPF, 1987). This potential is affected strongly by distance to the shoreline if currents are predominantly onshore/offshore as, for example, in the lower intertidal zone just before and after low water. At other times, net currents in the region tend to be alongshore, as shown by the frequency and orientation of spits on the Pacific and the Puget Sound coastlines (Schwarz, 1985; Komar, 1985; and Downing, 1983). The possibility of dispersed oil, compared to untreated oil, reaching the shoreline is reduced (in areas of good water exchange and vertical mixing) because dispersed oil moves with water currents and not under the influence of wind direction. An effective operation can protect sensitive resources, so a decision based strictly on the distance of the oil from shorelines does not take into account all applicable factors. At entrances to harbors, marshes and other sensitive areas, application of chemical dispersants can be conducted from vessels close to shorelines if limited to the ebb tide phase. The same may also apply to marine areas offshore of the major river deltas because dense saline water displaces the freshwater outflow from the distributary channels on the flood tide and at high water. Surface waters thus are outflowing at all tidal stages (Downing, 1983).

The aerial application of dispersants is best addressed by consideration of distance to shoreline, although this application is also affected by wind direction and velocity.

At large distances from the shore, especially in the case of relatively small spills, natural dispersion will normally obviate any need to consider use of chemical agents. If the residence time of the surface slick is less than the estimated time taken to reach shorelines or sensitive resources (including offshore feeding aggregations of seabirds or marine mammals), then dispersants use is not recommended. If accessible and calm enough, mechanical recovery methods could be attempted.

2. Sea State. Sea state is an factor in any decision to use or not use dispersants. The primary factors affecting sea state are wind velocity and direction, topographic features, including water depth, tidal currents, and vessel bow waves and wakes. Generally, as sea state, and therefore energy levels, increase, dispersants become more effective because of effective mixing combined with enhanced natural dispersion and delays in emulsification caused by the sea state. However, at these high sea states, the benefits from the dispersants themselves may be minimal because the sea state itself creates an effective nautural dispersion. At some intermediate sea state (2 and above) the processes of emulsification are very rapid (Van Oudenhoven, 1983). Chemical dispersion may not be effective, therefore, for very long if sea state is moderate. Unfortunately, there are no hard and fast rules which can be applied on the basis of sea state. However, chemical dispersants at sea states of above 5 may be more effective because of the delays in emulsification. This is important because emulsification can increase the volume of pollutant by up to four times, due to the incorporation of water. Application of dispersants at higher wind speeds is, however, prone to higher rates of wind drift.

When concentrates were first introduced to disperse oil, there was already in place the established practice in Europe of hydrocarbon-based dispersant spraying followed by immediate agitation. Agitation was applied by surface breaker boards which were towed by vessels or by spraying with fire monitor hoses. Now that dilution of the concentrates has been shown to be less effective than neat concentrate (Cormack and Martinelli, 1979), it is possible that breaking waves and high current shear are no longer necessary to a successful operation, because longer contact times will be available. The use of breaker boards, at least for small spills, may be an effective means of extending the controlled use of chemical dispersants into inshore waters which are calm but which otherwise are not a factor limiting the use of dispersants.

Taking all of the sea state factors into consideration, wave energy is unlikely to be generally sufficient to optimize use of chemical dispersants in the extreme southern inlets of Puget Sound, in much of Hood Canal, in Saratoga Passage and Port Susan, and, finally, in the open coast estuaries, even though winds are frequently funneled parallel to the long axes of the inlets. Water depth is seldom a limiting factor on wind wave generation in Puget Sound (Downing, 1983). However, it is important over tidal flats, in the nearshore zone, and in the Pacific estuaries. Shoaling waves at pacific estuary mouths, particularly during ebb tides and periods of high freshwater runoff, however, may produce extremely turbulent conditions. The various factors and degree of uncertainly underlines the importance of reconnaissance of the spill site before decisions are made regarding dispersants, rather than reliance on general weather reports.

3. Meteorological Conditions. These are a great number of meteorological processes which affect the physical behavior of untreated and dispersed oil slicks. Most important of these is wind. Wind affects processes which operate on both untreated and on dispersed oil for the most part near the water surface. The subsurface vertical turbulent diffusion process becomes dominant in the case of dispersed oil (National Research Council, 1989). The influence of wind on sea state is important to predictions of dispersant effectiveness. The wind patterns vary seasonally and with location to produce a varied wave climate in combination with the coastal topography, bathymetry, fetch and tidal currents (Downing, 1983).

Flow of air is generally from the west and southwest in the Pacific Northwest. In combination with fetch width and length, this means that wave action is greater on the open coast of Washington and Oregon than in the inland waters. Wind directions are influenced by topography, and generally trend east-west in the strait of Juan de Fuca and north-south in Puget Sound. The inland waters are likely to experience maximum significant wave heights only 1-2 hours after the wind starts to blow (so-called "choppy" waves), in contrast to almost 24 hours on the open coast. However, significant wave heights will be almost five times greater on the open coast after one day (approximately 8 m) (Lilly, 1983). Within Puget Sound, winds tend to be stronger on the eastern side than the western side, and in much of the southern Puget Sound lowland winds are generally light and variable in direction. This means that in general, wind velocity and direction are less likely to produce wave conditions conducive to chemical dispersion inside Puget Sound, particularly western Puget Sound, than on the open coast.

Near-gale wind speeds may also limit the response to an oil spill by causing wind drift losses of dispersant or by preventing aerial spraying and surveillance operations. Conditions that prevent deployment of aircraft, however, are unlikely to permit mechanical recovery operations except in harbors, marinas or high in the intertidal zone during low-water periods. Consequently, the effects of extreme wind speeds are rather similar to those of short day lengths; they limit both chemical and mechanical recovery techniques. However, one advantage of the dispersant option in exposed localities is that there are no items of equipment (such as booms or skimmers) which are vulnerable to high wind speeds. Under extreme conditions such equipment can drag moorings and end up as oiled trash, sometimes suspended from overhanging vegetation.

4. Seasonal patterns: Wave climate is directly linked to general and seasonal wind patterns. Year-round, southwest and west wind directions impinge on the open coast and produce significant wave heights which average approximately 3 m (calculated from mean wave heights exceeding 1.7 m, quoted in Thompson and Harris, 1972). In winter, wave heights and the frequency of storm waves are generally greater. Under offshore average conditions, therefore, mechanical recovery operations are likely to be at or above their upper limit of feasibility. Whereas, dispersants are less likely to be needed at sea states of 5 and above, it is evident that the operational window offshore is wider for dispersants than for mechanical recovery. It is also possible that naturally dispersed oil will resurface when winds subside (NRC, 1989).

Inside Puget Sound and the Straits of Juan de Fuca and Georgia in winter, the directional pattern and speed of winds are more variable. Southerly winds prevail over Puget Sound and Bellingham Bay, and these are generally higher in velocity further northwards. Wind speeds in winter at Whidbey Island exceed 8 m s^{-1} (16 knots) for more than 10 days per month, whereas the equivalent figure at Olympia is five days per month (Downing, 1983). Taking wind speed alone as a factor influencing sea state, this suggests that even in winter, the southern extremity of Puget Sound is unlikely to have sea-surface energy levels high enough to optimize effective use of dispersants. In winter northerly winds dominate the international waters of Haro Strait and that easterly, strong winds (average >18 knots) dominate the Strait of Juan de Fuca. In these more exposed waters, the most energetic wave action in winter can result from arctic air under high pressure leading to strong northeasterly winds persisting for up to six days.

In summer, the wind directions are usually northwesterly to westerly on the Pacific Coast and in the Straits of Georgia and of Juan de Fuca. In the latter, winds are often augmented by a sea breeze which is caused by differential heating over land leading to a rise in the continental air mass. The resulting pressure gradient can draw in oceanic air at recorded velocities of over 16 knots at frequencies of 15-21 days per month between June and August at Port Angeles. Elsewhere summer winds tend to be <9 knots (Downing, 1983).

Air temperature and rainfall also affect sea state. Cold air temperatures have the effect of increasing air density, so that the prevalent velocity of wind has more effect on wave generation. There may be seasonal implications of this process, for example, if chemical dispersants are not considered in winter because of low reported wind speeds. It is consequently important to inspect sea state at the proposed site of chemical dispersant use. Rainfall, if heavy enough, can have the same effect as high river discharges. Two other factors that are significant are (1) boundary layer salinity reduction, since dispersants are not always effective at reduced salinity and (2) the effect of wave-damping caused by freshwater stratification. The latter is of similar importance to the wave-damping caused by very extensive oil slicks, and may have some retarding impact on the processes of emulsification and dispersion.

Air temperature may also have a direct effect on the chemicals by increasing their viscosity at low temperatures. When the ambient air temperature is less than 0°C for long periods, pre-warming the dispersant before application may be necessary. The only candidate product for which this would be necessary might be Corexit 7664, although surface-collecting agents should also be stored in insulated containers when ambient temperatures are below freezing (EPA, 1989).

5. Fog: Persistent fog is relatively frequent in Washington and Oregon under the light wind conditions and clear skies of high barometric pressure systems. Heat escapes from the surface of the land during the night, and drifts seaward, particularly over cool inland waters, to produce radiation fog. Sea fog is more common in the Straits of Juan de Fuca and offshore. Fog can form when moist air is cooled beyond the dew point by cool ocean currents, and is common from California to Washington. Sea fog is resistant to winds of up to 25 knots and when high pressure is prevalent offshore, winds will frequently blow sea fog in from the western Strait of Juan de Fuca. Heavy fog (visibility < 400 m) occurs on average at some point during 59 days per year at Tatoosh Island, compared to 40 days per year at Port Angeles (Lilly, 1983). Radiation fog occurs on average during 92 days per year at Olympia and from 30-53 days per year at Tacoma and SeaTac International Airport. Although these patterns are reasonably consistent, it is difficult to predict the severity or persistence of fog episodes.

Fog episodes will, however, have a direct bearing on the feasibility of aerial dispersant application since most visually-guided air operations will be curtailed when ground-level visibility is less than 800 m and cloud ceilings are of the order of 60 m. Ceilings of 100-130 m are likely to cause some restrictions. It is doubtful that much useful work can be done at sea in such conditions, even though instrument-guided takeoffs and landings are possible at the major airports in conditions worse than this. The probability of persistent fog is relatively high at the mouth of the Straits of Juan de Fuca and in the extreme south of Puget Sound.

Seasonal incidence of fog is summarized by Lilly (1983). The available data, shows that peak occurrence of fog in the Strait of juan de Fuca is mid-summer, whereas in Puget Sound, the peak occurrence is October. Between Tatoosh Island and Port Angeles there is a 50 percent probability of heavy fog in August, which would not appear to be a good month to plan to use aircraft to apply chemical dispersants to an oil spill. However, it should be noted that fog patches will often clear during the course of a day, so the data on fog occurrence should not be over-emphasized.

6. Bathymetry. Bathymetry plays an important role in the successful application and environmentally acceptable use of chemical dispersants. The effect that water depth and nearshore morphology may have on wave and current form has already been described. The absolute water depth has often been used as an arbitrary limiting factor in dispersant use decision making, because depth acts

as a surrogate for more complex concepts such as dilution and mixing in the water column.

7. Sea Surface Temperature. The effect of sea-surface temperature on oil viscosity and behavior is an important factor in cleanup decision making. In winter the pour point of PBCO is likely to be reached after about one day. Mean water temperatures are of minimal significance, if, on the day of an oil spill, the water temperature is appreciably lower than normal. Sea water temperature can affect dispersant effectiveness directly as well as indirectly through changes in oil viscosity. The direct mechanism appears to be due to greater water solubility of some surfactants at low temperature. This means that the dispersants do not diffuse into the oil.

8. Suspended Particulates: Suspended particulate matter (SPM) is of potential concern due to the possibility of enhanced sedimentation of oil droplets. In areas such as delta mouths and in sheltered areas where fine muds have accumulated, the water column is often highly turbid, particularly after storms. This is the result of a combination of factors, such as:
(1) Wave base affecting shallow subtidal mud banks on the muddy intertidal at high water;

(2) Sediment discharge from erosional river catchments (e.g., relatively unprotected by snow or vegetation); and

(3) Estuarine circulation trapping SPM at the head of a "salt-wedge";

(4) Elsewhere, algal productivity may be the dominant factor in formation of SPM.

Areas where these processes may be important tend to be in shallow, nearshore situations where chemical dispersants would perhaps not be considered in any case. However, in Skagit and Whatcom counties, numerous rivers contribute to nearshore turbidity (and reduced salinity) particularly in the Whidbey Basin. Bellingham Bay (Nooksack River) and Commencement Bay (Puyallup River) and the southern open coast of Washington (Columbia River) are further areas to consider.

Although the exact relationship of SPM to the behavior of oil is not well described, there is a concern to ensure that the mid- to longer-term sedimentation of oil is not increased by use of dispersants. The concern is that once adsorbed to settling particles, the dispersed oil will become part of the muddy and possibly anaerobic subtidal, settled mud deposit. In this environment, biodegradation rates are much slower than in the near surface water column. Evidence from studies by Mackay and Hossain (1982), Harris and Wells (1979), and Little t al. (1981) suggests that particle affinities and/or settling velocities are not as high for dispersed oil suspensions as for oil alone. Wilson (1985) has provided further evidence that chemical dispersion does not increase sedimentation. Intuitively, a reduction in oil/water interfacial tension will reduce adhesion of oil droplets to solid surfaces. Nevertheless, since high SPM concentrations may be present in some nearshore waters of Washington and Oregon, it is recommended that caution be exercised at SPM concentrations of >100 mg l^{-1}. This figure is an arbitrary threshold value and may err on the side of caution.

9. Salinity: Salinity has been mentioned already in the context of surface freshets and stratification. It is important to know whether candidate dispersants are effective at reduced salinity. For example, Corexit 9527, 7664, and 8667 are all unlikely to be effective at salinities below 10‰. Corexit 9550 was designed for viscous oils and mousse, and was intended to be effective in salinities as low as <1‰. However, the areas of interest in the inner reaches of Puget Sound do not attain this low salinity.

Salinity can also be used as an index of mixing and residence time in the inland waters.

Logistical Considerations

1. Availability of Equipment. Logistical questions must be answered before a successful dispersant spraying operation can be mounted. Since much of the equipment is specialized, suppliers and technicians conversant with operational procedures must be organized well in advance of a spill. With any large spill response, sophisticated remote sensing imagery is an advantage. The necessary equipment for a mechanical recovery operation is now available for small and medium-sized spills in the Pacific Northwest. In the event of a much larger spill, more equipment would be staged and brought in, or even manufactured from available components, as became necessary after the "Exxon Valdez" incident. Similarly, much of the equipment for aerial or boat dispersant spraying is already available in the U.S.A.

Aerial spraying from large aircraft is best carried out by specialists, such as Biegert Aviation (AZ) and Conair Aviation Ltd. (BC). If the time taken to reach the decision to use dispersants combined with the time taken to muster (concurrently) these emergency facilities exceeds the time taken by the oil to reach shorelines (1-12 hrs) or emulsify beyond 2,000 cSt (4-8 hrs in winter), then preferably the equipment should be made more locally available. For large spills, the Airborne Dispersant Delivery System (ADDS) can be maintained locally (at high cost) and deployed by C-130 from any airfield with runways longer than 1500 m. Its capacity suggests that in theory a 3,000 to 5,000 t spill could be dispersed in one day (API, 1986).

ITOPF (1982) has given an example of appropriate planning for dispersant use. In a 4,000 t spill under optimum conditions, it would take about 200 t of dispersant concentrate applied within 12 hrs of daylight to effectively disperse the spill. This could be achieved using one DC-6. "The simultaneous operation of 10 Piper Aztecs or 20 Piper Pawnees to provide equivalent treatment capability would present practical difficulties" (ITOPF, 1982). Close to shore, however, the selective spraying of individual slicks of freshly leaked crude oil which threatened shorelines was very effective after the Betelgeuse explosion in Bantry Bay in 1979. This was carried out by one Piper Pawnee (Nichols and Parker, 1985).

2. Proximity of Equipment to Spill Location. Appropriateness of chemical agents

to spill site conditions is assessed partly in advance of the spill and partly at the time of the spill. Dispersant effectiveness will depend on the nature of the oil (its degree of weathering and emulsification) and the selection of a suitable dispersant type. In practice, effectiveness will also depend on the selection and use of an appropriate delivery system (API, 1987). The method of application is, in turn, influenced strongly by the size and location of the spill, in addition to the availability of suitable dispersants and equipment (ITOPF, 1982).

Dispersants are not currently stockpiled in the study area. Products selected should be of proven effectiveness on PBCO, and Alberta Cold Lake mixtures with condensate and diesel. Corexit 9527, 9550, 7664, and 8667 are all at least 25 percent effective on Bunker C (No. 6 Fuel Oil) according to the National Contingency Plan product schedule, published by the EPA. (Only products listed on the schedule may be used in the U.S.A.). This effectiveness on fuel oil, and the majority of the literature summarized by NRC (1989), would indicate that these products are likely to be satisfactorily effective on the oil types of interest locally, at least on those oils amenable to dispersants. Alberta Cold Lake crude oil is mixed with 20-30 percent condensate to a viscosity of 23 cSt at 40°C with a pour point of -60°C. As such it should be amenable to dispersants, at least when fresh.

In general, the speed of response is of primary importance to a successful dispersant operation, so aircraft will usually provide the best option. Small airplanes and helicopters are adequate for smaller inshore sills (<100 t) or spills which have not spread over wide distances. However, their usefulness is limited even in small spills when the distance to refueling/reloading airports or dumps is more than a few miles. Spraying from vessels, if available, may be a better option under these circumstances. Consequently, for spills occurring of the Pacific coast and in the Western Strait of Juan de Fuca, large fixed-wing aircraft offer the most appropriate platform for dispersant application.

To optimize a cleanup operation, however, a number of site- and slick-specific questions will have to be addressed at the time of the spill. Clyde-Woodward Consultants, 1978). Further checklists are provided in the API Model Plan for Dispersant Use (API, 1987). The need for rapid response would necessitate that locally available "first-aid" stockpiles should be maintained at a few strategically selected airfields, and contracts for rapid replenishment be already placed. Turnaround time can be reduced if, for small spills, bucket/nozzle systems can be deployed from helicopters, or drums of dispersants can be pre-loaded into quick loading pump vehicles. These could be transferred along with fuel trucks to remote locations, where a helicopter-based spraying operation could be mounted.

For a large spill 30 miles offshore (which was, however, moving onshore), a C-130 round trip of 150 miles from McChord Airfield would require on-scene support in the form of continual spill surveillance (probably by helicopter) to guide the larger aircraft. Assuming a total of about 3 hours per sortie and about 400 t of oil dispersed per sortie, on a winter's day an oil spill of about 1200 t could be tackled by one C-130 aircraft. This is not an over-optimistic assessment, but it is clear that only the thicker parts of the slicks and those slicks threatening the most sensitive resources could or should be dispersed if the spill exceeds ~2000 t. Unless more aircraft were available to strike on the first day or the airfield were nearer (e.g., Hoquiam, La Push, or Port Angeles), it is likely that some oil would remain, and in winter this would probably not be dispersible the next day. For spills offshore, the smaller airfields may offer better turnaround times. For example, at Hoquiam, facilities are adequate for C-130s, which could satisfactorily reach most threatening spill locations offshore. Alternatively, the nearby airfield at Ocean Shores, although with a runway suitable only for aircraft up to DC-3 or F-27 in size would be strategically located for an offshore spill. Ocean Shores could cover areas of the coast between "neighboring" airfields at Quillayute (La Push) and Astoria.

Fairchild International airport at Port Angeles would be the logical choice for response to a spill anywhere in the Straits of Juan de Fuca or northern Puget Sound. Port Angeles would also probably be the command center and would have additional communications facilities. Consequently, unless there was an overriding proximity of the spill to other, smaller airports such as Anacortes, it would probably be the best airport for responding to spills in the inland waters. On the other hand, Bellingham might be the best alternative to Fairchild under the persistent sea fog conditions of the Strait in late summer. Bellingham offers all the runway, fueling, and instrument facilities of a modern airport, and a closed runway on the west side which could be utilized for dispersant operations, including contaminant traps in the event of spillage. Bellingham is also very close to some of the most sensitive shorelines and vulnerable resources such as eelgrass beds, marshes, and wintering and migrating birds.

Fort Lewis (McChord) would be the most appropriate airfield for large-scale and staging operations, particularly if the spill were "federalized," having necessary experience of state/federal operations via EPA and DOE. It is probable that almost any location in the study area could be rapidly accessed by properly equipped aircraft, provided weather conditions were reasonable. Helicopters have the advantage of maneuverability in combined spaces (e.g., near pocket beaches). Some attention to fitting out helicopters and light aircraft for marine operations (e.g., pop-out floats, radar altimeters, and Loran) would be needed either to ensure compliance with FAA regulations or to provide greater safety in the very low altitude flight necessitated by dispersant application.

3. Availability of Trained Personnel. This would not constitute a logistical problem, provided integrated ground and air crew training and simulated spill exercises became part of the contingency plan. In particular, integrating with sea-going operations would be essential, so that spotter aircraft could direct appropriate equipment and personnel to optimum working locations in terms of slick thickness, resource protection priorities, etc. For large spills, personnel should be available to operate side-looking airborne radar (SLAR) and UV/IR Line Scanners, the latter potentially permitting remote sensing of the spill in the dark (Cormack et al., 1987). The proper identification of slick thickness, monitoring of dispersant effectiveness, and transfer of this information to supervisors of other parts of the operation is best carried out from the air, but in poor visibility this aspect of spill control must be duplicable at sea. Control of operations is facilitated by buoying of the main slicks, which may be an effective means of keeping track of the movement of surface slicks.

There is a requirement for off-the-shelf modular systems of nozzles, spray booms, and pumps. Time can be saved this way, by avoiding the necessity of adapting incomplete spraying systems to vessels of opportunity, which has delayed some cleanup operations. The importance of proper calibration of dispersant spraying systems is not to be underestimated and is best undertaken by trained personnel.

Although new technology will take some adapting to, the aerial and sea-going operations should be supported by the skills of pilots, engineers, and communications staff which already exist in the region. The local knowledge and prior experience of several aviation companies in oil spill response will be invaluable. Experienced pilots and operations managers exist in Seattle (Boeing Field), Portland, Everett, Port Angeles, and Forks. Some of the helicopter pilots are experienced in forest fire emergencies. This is transferable technology, just as crop-spraying experience has been in other areas.

Trained personnel will be required for the task of ensuring compliance with state regulations and the Occupational Safety and Health Act 1970 (OSHA) on oil and dispersant handling safety procedures. Potential concerns are eye and skin irritation, in addition to awareness of fire and explosion hazards and the risks of slipping on oily or dispersant covered surfaces.

4. Application of Dispersants. In all cases, the intention is to reduce the overall ecological damage of the spill by spraying only those parts of the slick which threaten vulnerable coastlines, offshore bird or mammal concentrations, or other sensitive resources. The intention is also to spray slicks only when adequate control can be maintained over (1) droplet size and (2) dosage. Control is easier if calibration and testing of the spray pump and nozzle assemblies has been carried out in advance with the actual product in use and at ambient temperature. However, the accurate control of spray droplet sizes (optimum value, 350-500 μm; API, 1986) is complicated by crosswinds, so that it may be preferable to spray only with a head wind or using larger droplet sizes (e.g., 600-800 μm; ITOPF, 1982). The control of optimum dose rates is at best approximate, since the geometry of the spill will usually confound accurate assessment of oil quantities once the slick has fragmented into windrows. Spraying is most effective if concentrated on brown or black oil, preferably at slick thicknesses of >0.1 mm (but less than 0.5 mm if mechanical recovery is underway elsewhere in the slick). Monitoring the effectiveness of treatment is difficult when slicks are very thin because the chemical can often act as a herder and give the mistaken impression that dispersion has occurred. To be confident of success, a characteristic brown plume in the water and verification that surface oil is decreasing are needed.

For most concentrates, an effective ratio of dispersant to oil lies somewhere between 1:5 and 1:30. Both concentrates and Corexit 9550 can be sprayed from the air. They should not be pre-diluted. Indeed, if dispersion does not occur at the lower dispersant-to-oil ratios, then repeat applications may be necessary. Alternatively, the ratio can be increased by adjustment of pump rate or aircraft speed. Because it depends on verification that dispersion is occurring, a trial-and-error approach to oil-to-dispersant ratios is recommended in the field. A great deal of planning information can be gleaned from the API Model Plan for Dispersant Use (API, 1987), from ITOPF (1982 a and b, 1987) and from the

Dispersant Application Manual (Woodward-Clyde Consultants, 1978). The manual also covers applications from surface vessels and gives a comparison of the potential areas treatable, the time required, and coverage by different spraying systems. The API model plan includes useful summaries of the main decision trees, including the EPA computer version.

5. Diffusion and Dilution in International Waters. The consistency of the proposed action with regulatory procedures in neighboring and other regions of the USA and Canada is considered in Section VI. There is, however, the possibility of a logistical constraint arising from use of dispersants or other cleanup operations in the international boundary waters. It may be appropriate to employ trajectory modeling of surface oil slicks and of dispersed oil plumes in this region to further define the areas where dispersant use would not be advisable.

In the interim, the available literature suggests that current movements of surface waters tends from east to west in the Strait of Juan de Fuca. The deeper, more saline water tends to flow west to east, and diverge into the Strait of Georgia and the main basin of Puget Sound. The deeper water mass is similar to the Puget Sound deep water layer except that it is 0.9‰ more saline and about 0.7°C colder (Ebbesmeyer and Barnes, 1980). Unlike the deep water in the Admiralty Inlet region of the main basin of Puget Sound, however, there is little intermixing with the overlying water mass in the Strait of Juan de Fuca. The east-to-west surface currents combined with a diffusion "floor," would suggest that dispersed oil plumes are more likely to move east to west than across the international boundary. Therefore,provided chemical dispersion does not take place adjacent to (~3 km) the boundary, there will be less risk of dispersed oil impinging on Canadian waters than wind-driven, untreated oil.

Two of the largest oil spills in Washington were the "Arco Anchorage" spill of 775 t (238,890 gallons) in January 1988 and the "Nestucca" spill of 750 t (231,000 gallons) in December 1988. Neither spill was chemically dispersed and the spills were of an almost equal size. However, the "Arco Anchorage" spill occurred very close to international waters, and yet did not significantly affect Canadian shorelines. In contrast, oil from the "Nestucca" spill traveled along the entire coast of Washington from Grays Harbor, and affected shorelines on the west side of Vancouver Island. Plumes of dispersed oil are unlikely to cover this sort of distance.